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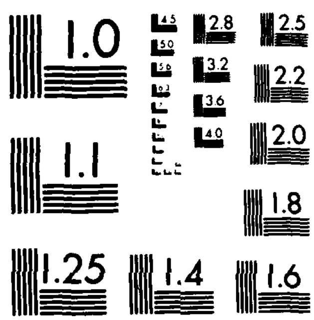

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EVALUATION OF DESIGN CRITERION OF THE
STRATEGIC EXPEDITIONARY LANDING FIELD

A Special Research Problem
Presented to
The Faculty of the School of Civil Engineering
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By
Richard Everett Burgoyne

In Partial Fulfillment
of the Requirements for the Degree
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APPROVED:

D. W. Halpin, Advisor, Date

P. H. Wright, Reader

D. O. Covault, Reader

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SUMMARY

This study concerns the relaxation of design criterion for the strategic expeditionary landing field. The design criterion are individually evaluated to determine underlying or governing principles. Each principle is then reviewed to determine the implied or hidden factors of safety. Criteria are then reviewed individually to determine the effects of relaxing that criterion. The evaluation is made to ensure the operational ability of the facility and the construction effort. The construction effort is evaluated for a given circumstance before and after the proposed criterion change.

The scope of this work is only that of construction effects and construction effort. The effects on aircraft are not evaluated other than to ensure that the aircraft's performance abilities have not been exceeded.

CHAPTER I

INTRODUCTION

The logistics and support facilities required to support modern warfare are vast and complex. Current contingency plans involve the movement of thousands of men and their equipment and supplies to any given operations area. The facilities required to both move these materials and support the troops have to be constructed. This construction effort must be completed as quickly as possible to support the combat operations. The facilities often resemble whole cities of several thousand people. Yet many of these facilities are vital to the overall outcome of the armed conflict. The desired and necessary goal is to develop and place in service these facilities as soon as possible. In its most recent armed conflict, the United States spent some $2 plus billion for the facility needs. In Vietnam over a ten-year period, the whole exterior of the country was changed by this vast building effort. (1)

In Vietnam, the necessity of the large facility complex developed relatively slowly, and the circumstances allowed for the contracting of an extensive consortium of large construction contractors to execute a considerable

portion of this effort. In order to be successful at modern warfare, the military must be able to provide for at least its interim construction needs. In this light, an extensive list of contingency plans exist. These plans include pre-engineered designs and facilities and the prepurchase and stockpiling of required materials. These actions can and should remove the longest part of the construction process. The prepurchase and pre-engineering has additional side benefit in allowing the personnel who are to construct the facilities to practice their tasks. Consequently, the only real unknown in the construction of these facilities is the final location. The selection of location can have a significant effect on the overall effort required to complete and place in service a particular facility. The practice construction of these pre-engineered components allows for the review of their functionability thereby ensuring that the required serviceability is provided. However, in order for the overall system to be serviceable, the site must be properly chosen and prepared.

The choice of site is often determined by the strategies or politics of the situation with the engineer concept only being able to agree that the components can be constructed on the site selected or stating that the effort required to do such is more than available. In this light, the documentation which directs the site requirements

for a particular component is at best general and always conservative in nature. This conservative side of the requirements often increases the effort required to construct and phase-in use a facility component which has a very short useful life expectancy. A review of these "canned" designs might be able to improve the flexibility of their application. Flexibility will most likely be created by increasing the range of conditions over which the "canned" designs can be implemented. For want of a better term, this increased range of application shall be called relaxation of design criteria.

The relaxation of criteria should be divided into three categories. First is that relaxation which would most likely render the facility unserviceable. This type of reduction in quality must be avoided. The second is a relaxation which would leave the facility fully serviceable in all but a very few situations. This type of relaxation if it is to be of any value must be fully examined, and the increased risks of the relaxed design be fully documented and understood. The benefits gained by reducing the construction efforts required could more than offset the increased risks. The third type of relaxation which could occur is the relaxation of a standard which has now been relaxed in civilian practice but not yet found its way into the military contingency plans. This type of relaxation still requires careful study as

the military uses may differ from the civilian and cause some increase in risk in the military situation.

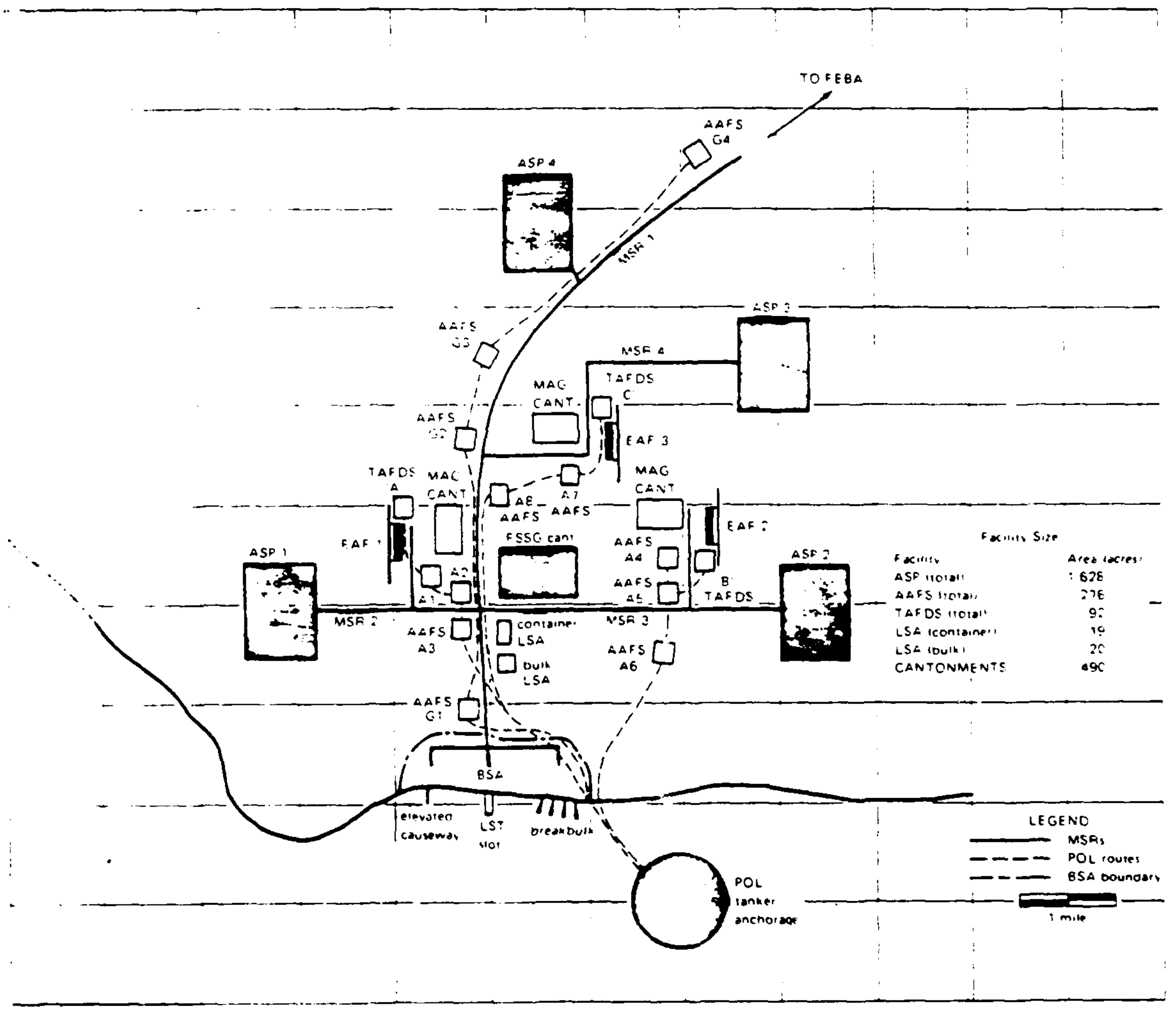
The type of criterion which appear to be the ripest for review are those which deal with site preparation. These criterion are established as a set of rules or guidelines for application by personnel who are not instructed in the engineering principles which control but are experienced in this type of field work. These criterion generally include drainage considerations, the site geometry, and soil/soil-stability of the site. Generally, these efforts comprise the horizontal construction effort. The vertical efforts are reviewed on the periodic installation of these types of components. However, on these practice installations, the horizontal factors are developed to a higher level and for a longer life expectancy than those which will be required in the expeditionary type of installations.

In short, the review of the horizontal construction criterion appears to offer an area where significant savings of construction effort can be achieved through careful review and evaluation of the existing criterion. This savings should not affect the useability of the facility or should carefully document any reduction of serviceability if any is anticipated.

There are several components of horizontal construction involved in the required support facilities. For example, the Amphibious Operations Area (AOA) is currently the

ultimate planned extent of the amphibious assault. The AOA consists of some 52 square miles of improved area for the many facilities to be constructed. (14) Figure 1 is a conceptual layout of the facilities. The facilities include a base camp, logistics area, fuel storage facilities, ammunition storage facility, airfield and interconnecting road system. The full extent of these facilities are to be constructed and operation in the order of 60 calendar days.

Further, there is a requirement to make each individual component functional for the entire duration of the construction period. This is accomplished by building a subelement of the final product first and then adding to it in stages to eventually construct the full facility. For example, the base camp area starts out as a clear area, then tents are added for several subfunctions. Eventually, tents are added for billeting and then slowly as the manpower and materials are available, the tents are replaced with the buildings. The medical and messing facilities receiving priority. In this manner, the base camp is kept operational (that is able to perform its function and still be upgraded). Other functions such as fuel storage and ammunition facilities are modular and added a piece at a time as they are required to provide capacity. One facility that does not fall in this practice as well is the air support facility.



Facility	Area (acres)
ASP (total)	1,628
AAFS (total)	276
TAFDS (total)	92
LSA (container)	19
LSA (bulk)	20
CANTONMENTS	490

Figure 1. Amphibious Operations Area Conceptual Plan. (14)

There is a need from the beginning for aircraft support in the quick resupply of required items and the evacuation of wounded. The problem of incrementing these facilities takes further planning.

The development of the Strategic Expeditionary Airfield (SELF) is in five steps. (12) The five steps are:

VTOL (Vertical Take Off and Landing)

VSTOL (Vertical/Short Take Off and Landing)

FAB (Forward Air Base)

EAF (Expeditionary Air Field)

SELF (Stragetic Expeditionary Landing Field)

Figure 2 sketches each of these steps. Generally, the VTOL is an AV-8 of helicopter pad and grows in stages into an 8000-foot runway, taxiway with sufficient parking apron for 96 fighter aircraft.

The SELF has several design criteria involved in its construction. These criteria are based on several different things. Some are a function of the aircraft performance, some a function of soil stability, and still others based on basic physics principles. The aircraft support facility, whatever its stage, is the most complex of the facilities in the AOA because of the interplay of all the different criteria bases.

Table 1 shows a list of the general items to be considered in the planning and design of an air facility.

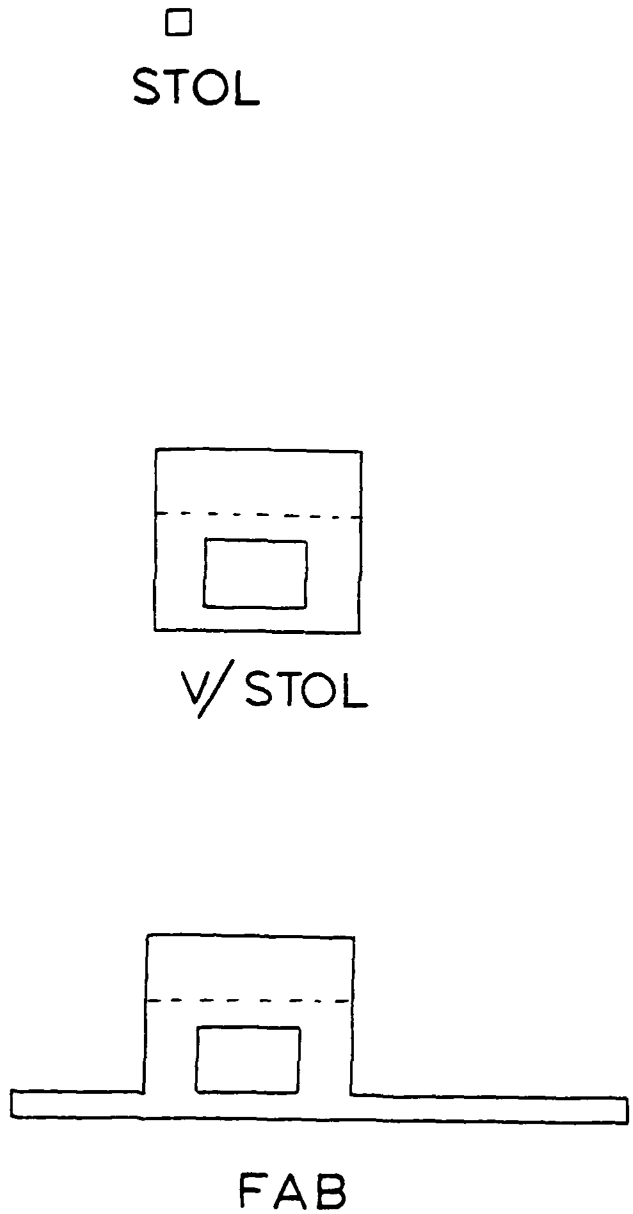


Figure 2. Five Steps of SELF Development.

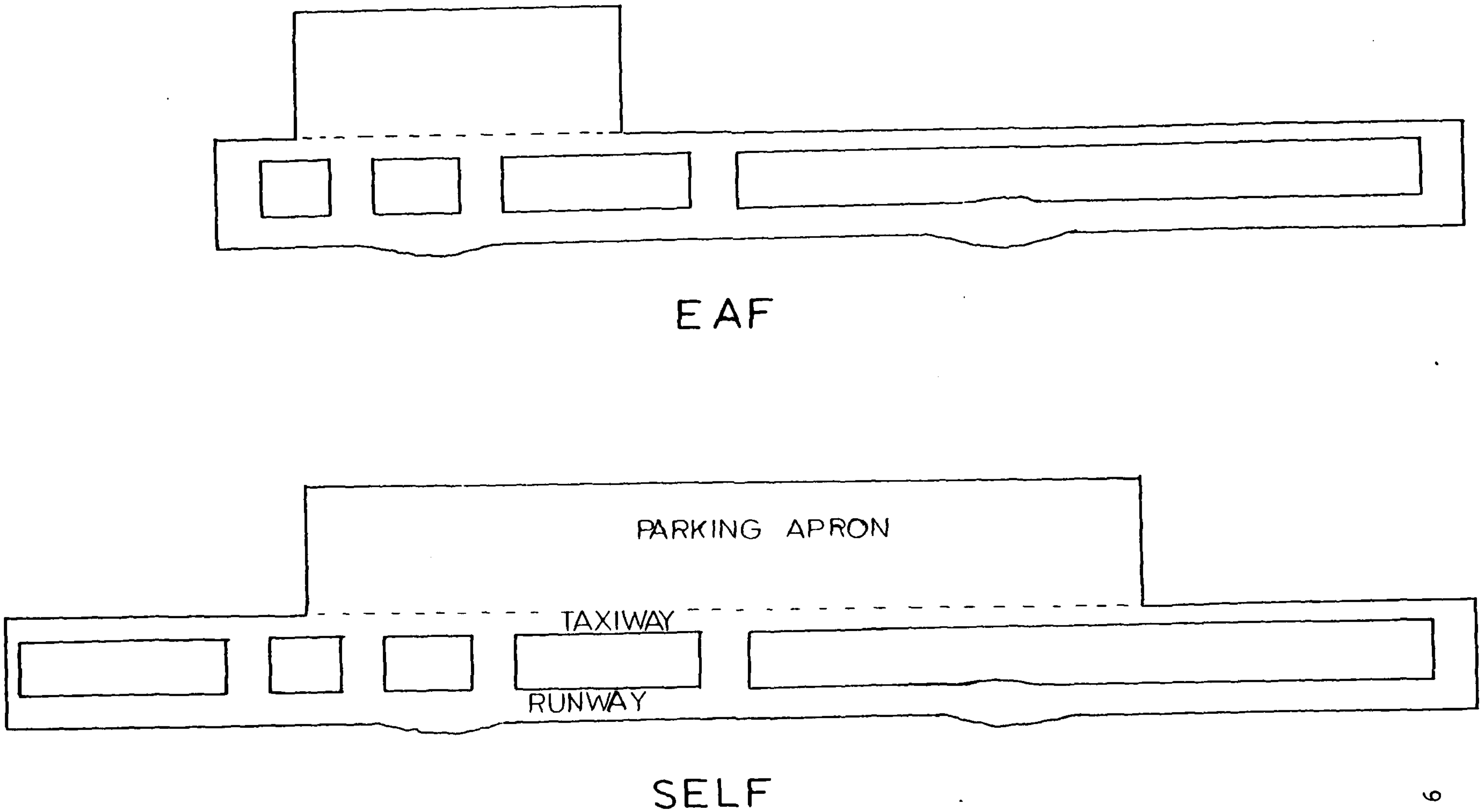


Figure 2. (continued)

Table 1. Comparison of Site/Environmental Parameters and Geometric Design Parameters

Design/Geometric Parameters \ Site/Environmental Parameters	Slope	Vegetation	Temperature	Elevation	Wind Direction/Speed	Aircraft Type/LandingGear	Runway Surface Mat	Work Force/Equipment	Runway Type	Weather
Runway										
Length			X	X		X			X	
Width						X				
Trans. Grad.	X					X				
Long. Grad.	X					X				
Taxiway										
Length									X	
Width						X				
Trans. Grad.	X									
Long. Grad.	X									
Parking Apron										
Length									X	
Width						X				
Clear Zone						X				
Overrun	X					X				
Separation Zone						X				
Lateral Safety Zone						X				
Approach Zone (Glide Slope)						X				
Dust Palliative									X	
Drainage									X	

The interplay can be noted by the several criteria or design parameters which are affected by more than one variable. Because of this interplay, the design criteria tend to be controlled by the most conservative which often is of a subjective nature. For these reasons, the SELF design criteria will be evaluated in greater detail to see what are the controlling factors and if these factors can be relaxed. If these relationships can be detailed for the SELf, then the principles should be applicable to the remaining facilities in the required AOA construction effort.

CHAPTER II

SELF CRITERION

One of the largest single construction efforts anticipated by the current contingency plans is that of an airfield. The construction of an airfield consists of several components. For purposes of this discussion, the efforts shall be divided as follows: horizontal effort (to include earthwork and drainage), pavement (to include matting, lighting, aircraft tiedowns, arresting gear, etc.), and vertical (hangars and other buildings). There are other components which are required to make an airfield fully functional. Such items as fuel depots, ammunition storage, and road systems are essential to the function of the system; however, since these components may not be associated with an airfield, they will be treated in their own right.

A recent (1976) installation of an expeditionary airfield occurred at Marine Corps Base, Twenty Nine Palms, California. (2) This installation was accomplished in a normal work schedule and required some six months to complete. The total effort expended is not clear. However, it is obvious that a construction effort requiring

six months to complete is not acceptable in the context of the contingency plans.

The time of construction is thought of in hours. The total time to assemble the basic SELF (matting, lighting, catapult, and communications system) is estimated as 17,941 man hours. (12) This effort is to be made in a 214-hour stretch with from 42 to 134 personnel working on the project. If this amount of effort were expressed in terms of 8-hour mandays, it would represent 2243 mandays of effort. The efforts to estimate and study the best assemble procedure has been intense.

With the goal of reducing the construction effort required to build such an expeditionary airfield, the design criterion are to be reviewed. The efforts required for both the vertical and paving construction are well documented and will not be further reviewed here. Instead, this effort will be directed at the so called horizontal effort.

The airfield built at Twenty Nine Palms is to be the prototype for the Marines SELF. The design criterion for the SELF is located in three separate sources. The first is the Army manual, the TM5-330. (3) The second is the final report on the efforts at Twenty Nine Palms. (2) The report on the 1976 construction at Twenty Nine Palms basically provides the shape and function of the SELF.

The TM5-330 provides information on the allowable slopes and drainage requirements. Third, some of the clearance requests are reduced by a letter from Colonel Billy Bouldin.

The SELF is to support a Marine Air Wing. The complement is up to 96 aircraft and logistics support aircraft such as C5's, C141's. The Marine aircraft consist of F4, A4, AV8, A6, and KC130's. The expected life expectancy (that is useable life of the airfield) is six months.

Prior to the discussion of specific standards or criteria which must be met, it should be pointed out that the desire is to develop a functional facility which will serve for a relatively short time period. Therefore, the effort to develop this facility should be minimized as much as possible. In relaxing standards, there is no advantage unless the construction effort and thereby time of construction can be decreased. However, by relaxing the standards, it is not implied that all future construction will be to this lower standard. If the site of the facility permits, the construction should be to a higher standard. In evaluating the efforts required for the construction, it must be assumed that a site which is "ideal" for the construction of that facility does not exist. Then to relax a particular standard would perhaps reduce

the required construction effort and allow the facility to become functional in a shorter time frame.

Generally, an airfield is defined by geometric items (length, width, clearance zone, etc.), drainage requirement, and operational needs. For the SELF, the geometric needs are defined by the final report on Twenty Nine Palms and the TM5-330. (2, 3) The drainage requirements are in the TM5-330. The operational considerations are assumed to be included in the foregoing requirements as they affect the construction efforts required.

The size of the SELF shall be determined by the Twenty Nine Palms installation and are as shown in Fig. 3. To determine the remaining standards, the TM5-330 will be used. The classification of airfields used in the TM5-330 does not include the Marine's SELF; however, by reviewing aircraft type which are to use the facility, the Rear Area Tactical airfield classification appears to perform the equivalent function. The full impact of an airfield is three dimensional, and Fig. 4 is provided as a general inventory of the dimensional data required to describe an airfield. In Table 2, an enumeration of the dimensional requirements is provided.

In order to discuss these various standards, they will be reviewed individually; hence, in the order of Table 2.

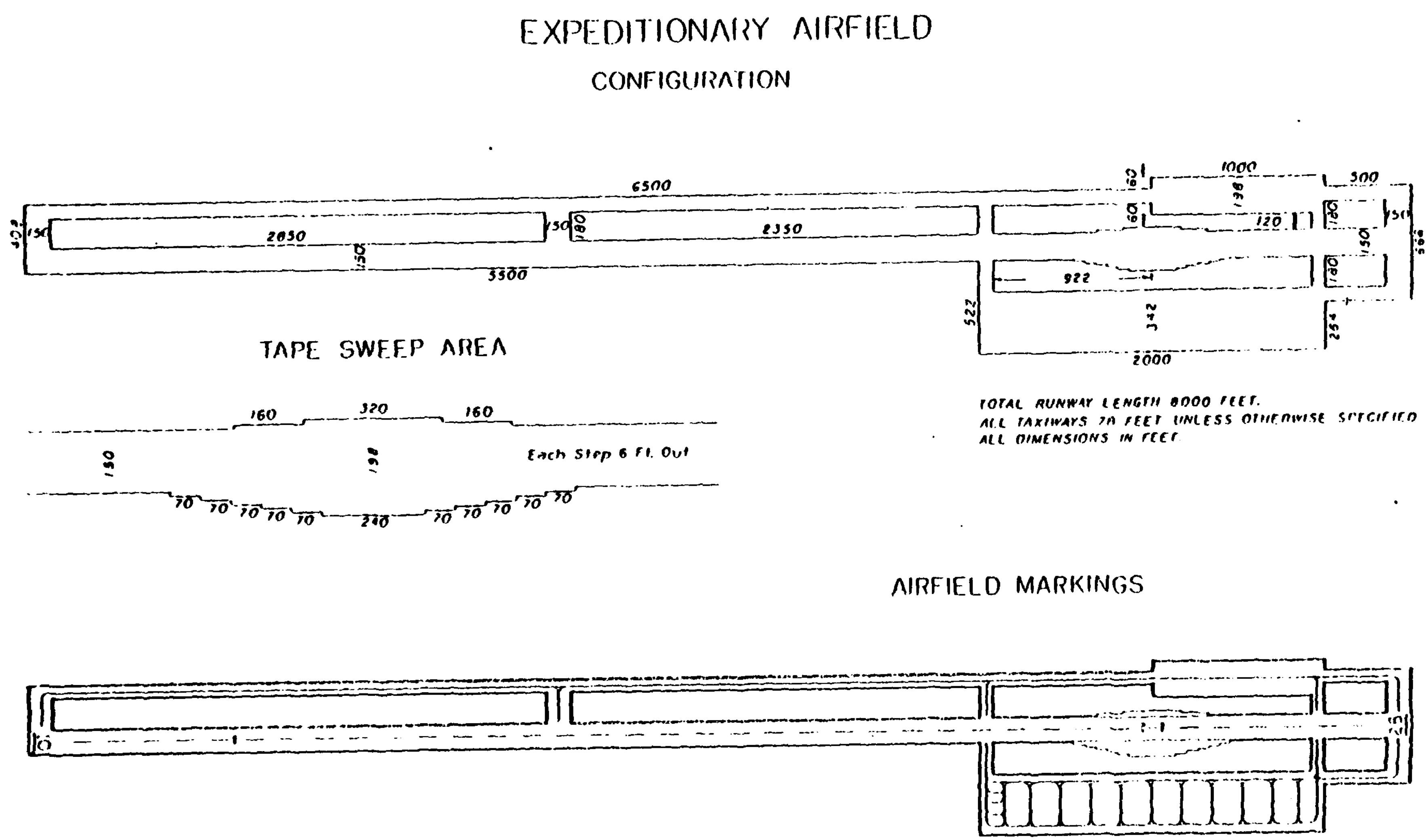


Figure 3. Twenty Nine Palms SELF. (2)

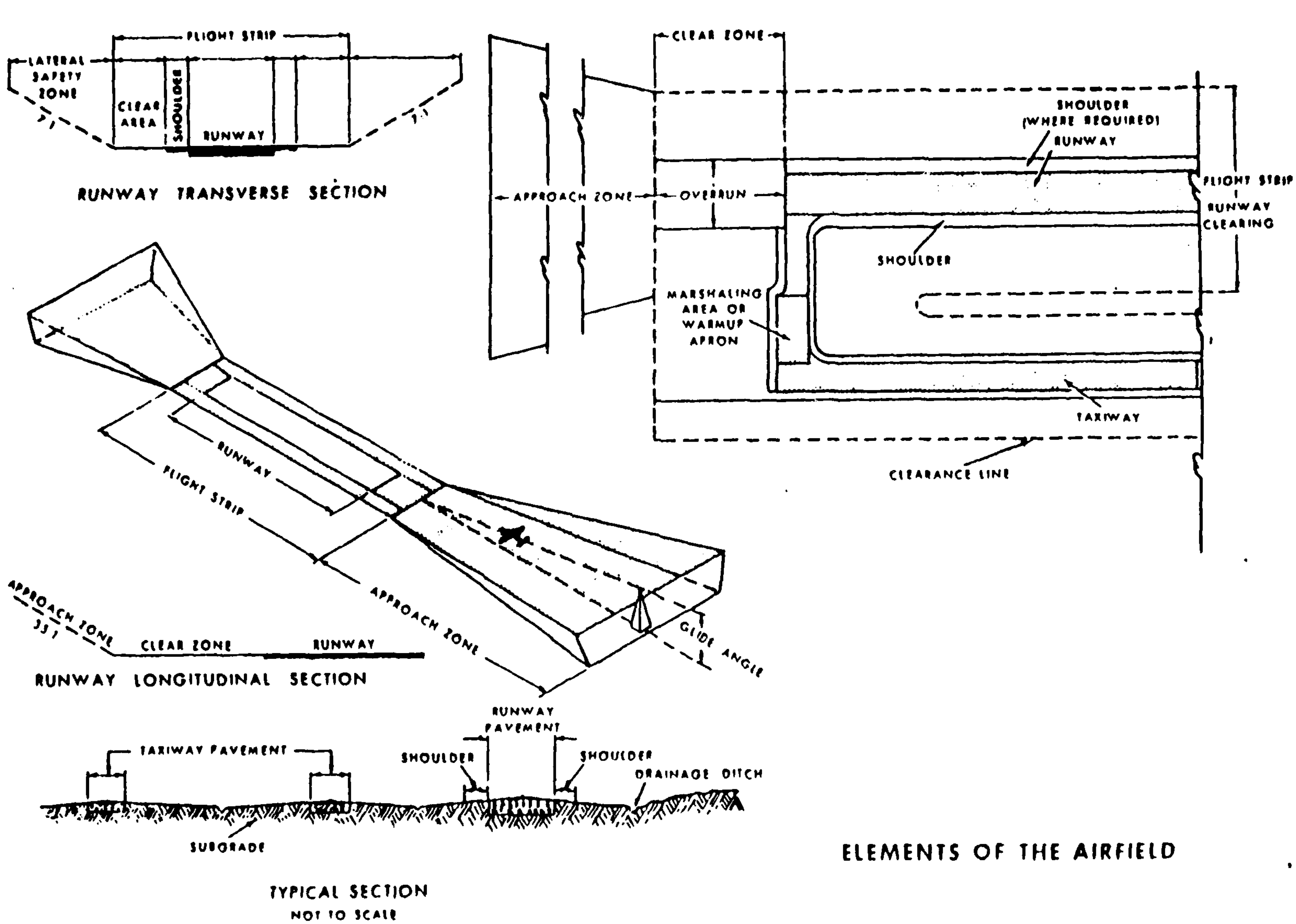


Figure 4. Elements of the Airfield. (3)

Table 2. Existing SELF Criteria.

<u>Runway</u>	
Length	8000 feet
Width	96 feet
Gradients	
Longitudinal	0 + or - 2.0%
Transverse	0.5 - 3.0%
Maximum grade change per 200 feet	0.33%
(Note the first 500 feet must have no grade change)	
Shoulders	
Width	20 feet
Length	Same as runway
Transverse Grade	1.5-3.0%
Clear Area	
Width	35 feet
Transverse Grade	5.0%
Over Run	
Length	500 feet
Width	96 to 288 feet
Lateral Safety Zone	
Slope	7 to 1
(This slope is to be maintained up to 150 feet height)	
Runway Approach Zone	
(Glide Ratio)	15 to 1
Length	25,000 feet
<u>Taxiway</u>	
Length	Same as runway
Width	78 feet
Gradients	
Longitudinal	0.0 - 4.0%
Transverse	0.5 - 3.0%
Shoulders	
Width	20 feet
Transverse Grade	0.0 - 5.0%
Lateral Clearance Zone	180 feet
Clear Area	
Width	65 feet
Maximum transverse grade	5.0%
<u>Parking Apron</u>	
Length	2,000 feet
Width (including 78 foot taxiway)	432 feet
Shoulder	
Width	20 feet
Transverse grade	1.5 - 5.0%
Lateral Clearance Zone	65 feet
Drainage	2-year design storm

Runways

Runway width. To determine the required length of a runway, several considerations must be made. They include ground run of the aircraft, adjustments to the local site and then a factor of safety. The longest ground run of the aircraft using the SELF is that of a F4 at 4000 feet. (3) (The C 141 and C 5 have longer ground run requirements under fully loaded conditions; however, it is assumed that these aircraft would arrive loaded and depart under a "light" load configuration.)

Elevation correction. 10% addition in runway length for each 1000 feet of elevation above 1000 feet. Assume maximum elevation to be 3000 feet (factor = 1.2).

Temperature correction. 4% length increase in runway length for each 10° above 59° Fahrenheit. Assume maximum temperature to be 99° (factor = 1.16).

Factor of safety. 1.5 for rear areas. 1.25 for forward areas.

$$4000 \times 1.20 \times 1.16 \times 1.5 = 8352 \text{ feet}$$

$$4000 \times 1.20 \times 1.16 \times 1.25 = 6960 \text{ feet}$$

It is then required that the length be rounded off to the next even 100 feet. Therefore, the above would become 8400 feet and 7000 feet, respectively. At 8000 feet under the above assumed conditions, there is a factor of safety of 1.44. The current minimum runway length is 8000 feet.

Each correction factor above also has factor of safety incorporated. These calculations are in accordance with the TM5-330.

<u>Runway width</u>. The width of 96 feet is provided for the logistical aircraft (C130's, C141's and C5's). These large aircraft require room for manuevering at take off and approach speeds. The TM5-330 recommends a width of 108 feet for fighter aircraft and 146 feet for heavy lift cargo aircraft. Therefore, there does not appear to be latitude for further reduction. The width of runway is influenced by aircraft wing span. The C5 has a wing span of 222 feet which means its wing tips will far overhang the runway pavement.

<u>Runway gradients</u>. Longitudinal gradient is limited for the SELF to 2.0%. Though for other types of aircraft the gradient may be increased to as much as ten percent by extending the length of the runway eight percent for each percent increase in gradient. This restriction seems severe. The restriction on longitudinal gradient is caused by the requirement of aircraft to be able to accelerate to flight speed within the length of the runway. The added task of climbing up a hill as the aircraft is accelerating decreases the rate of acceleration and therefore the length of runway required. Another aspect of this restriction might be the limitations of the aircraft electronics

packages. This aspect would have to be verified by electronic designers prior to any increase in acceptable gradients.

Transverse gradients are influenced by three factors. First is the required drainage. That is, there must be some transverse gradient to insure the prompt removal of water from precipitation. This minimum value has been set at 0.5%. (8) The relaxation of this minimum coupled with possible slight irregularities in the finish grade could lead to flat spots and the pounding of water. Pounding of water would have severe effects on aircraft due to the rapid change of available friction for breaking and turning. This pounding could lead to the loss of control of an aircraft which would not be an acceptable risk.

Secondly, is the coefficient of friction between the aircraft tires and the runway surface. Tire friction is of concern because of the large change in lateral force available between the friction force from a rolling while braking tire and one which has stopped rolling and is now sliding. Figure 5 demonstrates the large reduction in force. (5) AM-2 matting is required to have an anti-skid compound applied prior to use. This compound is required to have a coefficient of 1.0 wet or dry. (4) The coefficient of friction between tire and surface decreases as the relative speed between the two increases. (5)

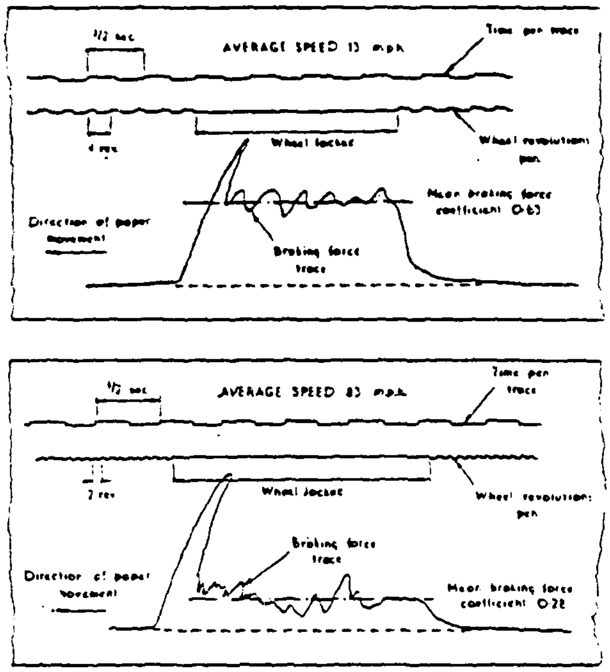


Figure 5. Typical Records of Braking Tests at Low and High Speeds. (5)

Messrs. Giles and Lander (5) have investigated the skid resistance as it is affected by speed. Figure 6 is a summary of their findings. The several graphs represent the findings of several different runway surfaces. Though none of their tests were conducted on AM-2 matting, tests of the skid resistance of matting have been conducted by the U. S. Army. Figure 7 is the results of one such test. (11) The tire at very slow skid speed has a coefficient of friction of approximately 0.68. This coefficient of friction is high due to the low rate of speed.

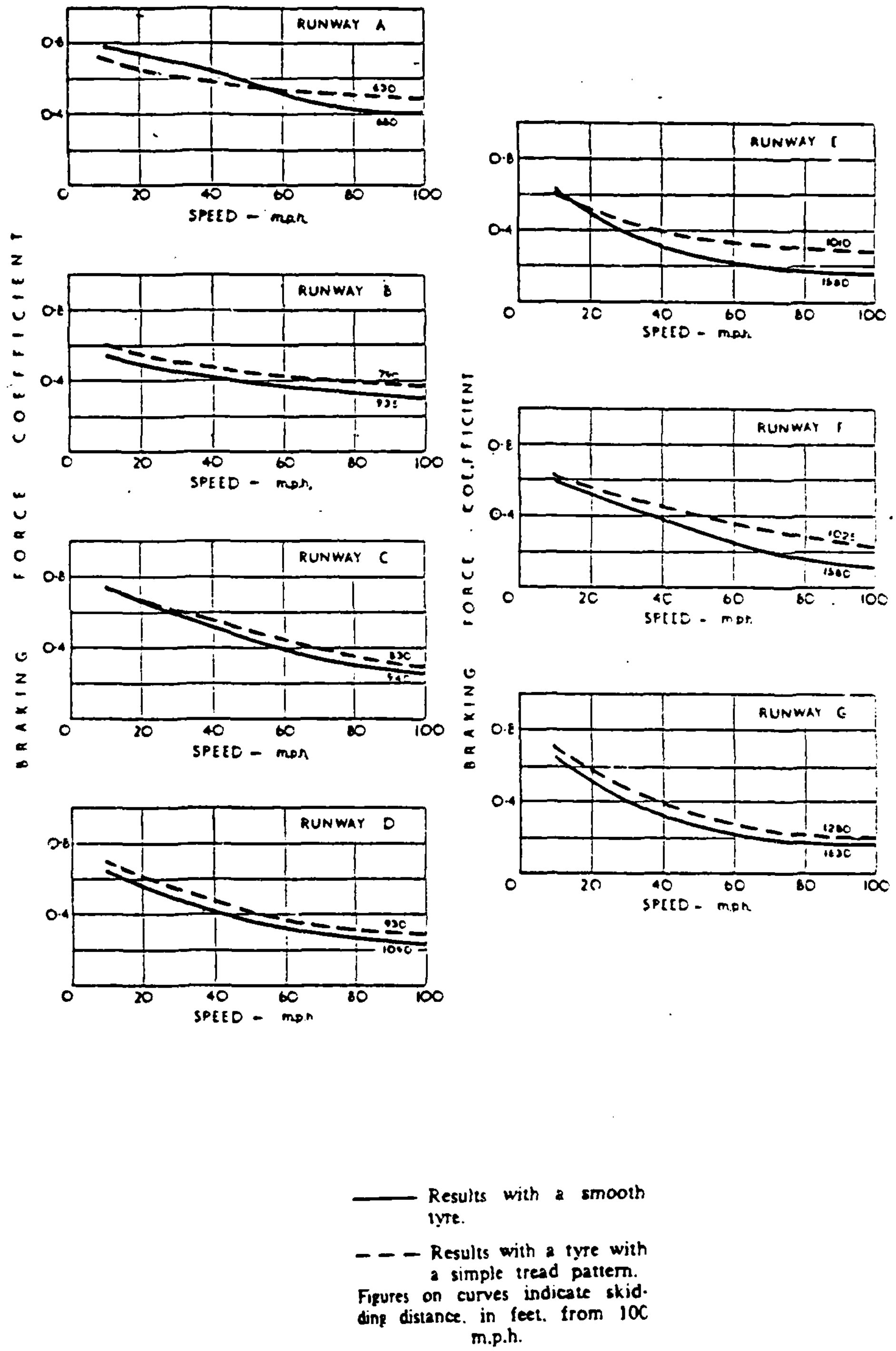


Figure 6. Curves Showing Results for Wet Runway Surfaces. (5)

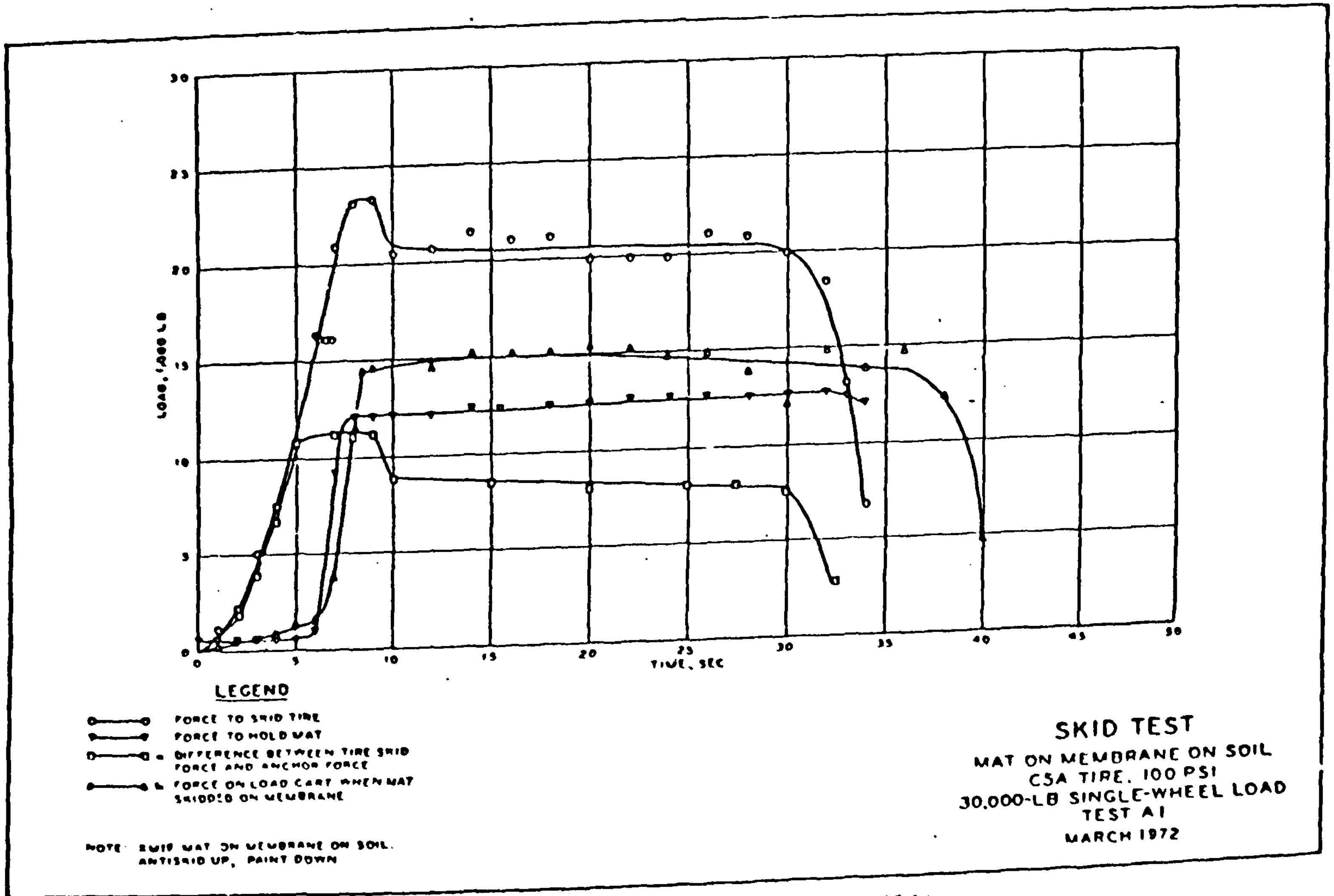


Figure 7. Skid Test on Matting. (11)

Considering the rate of speed as in Figure 6 and other factors, which serve to reduce the effective coefficient of friction (things such as usage, flake off of the anti-skid compound), an expected coefficient of friction in excess of 0.2 should remain at aircraft flight speed. This coefficient should develop sufficient friction force to allow for normal steering and lateral control of the aircraft. In braking the high speed portion is accomplished by means other than tire friction. Internal means as reverse thrusters and drag shuts and external means as arresting gear are used. The low speed braking should have sufficient friction available since the coefficient of friction increases with the reduction of speed. (5) In view of the above, the coefficient of friction does not appear to warrant the maximum transverse grade being less than three percent.

Thirdly, the aircraft must have clearance for their wing tips. An aircraft normally approaches the runway in a level (wing tip to wing tip) attitude unless a cross wind is present or the alignment is not exact and the pilot is trying to make final corrections. In a cross wind, the aircraft will dip one wing to cause the aircraft to slip in the direction of the wind and obtain wheel alignment with the runway. Sufficient clearance must be provided for the aircraft to perform these manuevers. An analysis of each specific aircraft and its clearance from the ground

will have to be conducted to determine if this factor controls the transverse gradient.

At the present, allowable of three percent, there has already occurred a relaxation of the standards from the TM5-330 where the maximum allowed is 1.5%.

Maximum rate of grade change. The maximum rate of grade change is controlled by two factors. First is the requirement of matting members to be continuously supported. That is, the matting member cannot act as a bridging member. This requirement is expressed as a maximum deviation of 1 inch in a 12-foot distance from a straight edge. Second, the bump effect of a rapid grade change is considered. This consideration is for the comfort of the aircraft and passengers. The effect of this bump can be to create a short flighting sensation at speeds close to flight speed.

Shoulders. The shoulders of the SELF are paved with AM-2 matting, the same as the main surface of the runway.

The length of the shoulders must be the same as the runway as the reduction of effective width partway through the length would create an unsafe condition.

The width of the shoulders is influenced by the same factors which influence the overall width of the runway and appear to have been reduced as far as possible.

The transverse slope of the shoulders is controlled by the considerations which influence the transverse slope of the runway with one additional consideration. If the shoulders slope down at a different slope than the runway, it could be possible to create a lateral force on an aircraft if that aircraft's landing gear were to stray across the change in slope. This factor would control the maximum difference in slope between the runway and shoulders. The concern of wing tip clearance would be resolved if the shoulders always sloped in a downward direction away from the runway. However, this could cause a "ridge" at the change of slopes which might adversely affect the aircraft.

Clear area. The functions of the clear area are two. The first is to insure sufficient clearance for the wings to clear any obstacle and a poorly centered aircraft not to encounter an obstacle. The effective width for this is 206 feet (96 feet of runway, 20 feet of shoulder on each side, and 35 feet of clear area on each side). A C5 has a wing span of 222 feet which means that its wing tips are already overlapping into the lateral safety zone. The second effect of this area is to make the pilot "feel" as if there is sufficient room for the aircraft (the lateral safety zone also helps in this "feeling").

Transverse slope is limited to 5.0% as a safety precaution to prevent the destruction of an aircraft from accident if it should stray over in the clear zone. In view of the limited life of the facility and the other hazards in the operations of such a facility, the increasing of this transverse slope in a downward direction does not appear to offer an undue hazard.

Overrun--Length. The length of the overrun is controlled or should be controlled by the distance required to stop an aircraft using the E-19 overrun arresting gear.

Overrun--Width. The inward width is controlled by the width of the runway. The outward width is controlled by the ability of an approach aircraft to make final corrections at this short distance from the runway.

Lateral safety zone. The lateral safety zone provides still a larger area free of obstacles for room in which a pilot might maneuver. Also, the area increases the pilots "feeling" of sufficient room for the aircraft.

Runway approach zone. The current standard for the SELF is 15:1 glide ratio for 25,000 feet. This is a considerable relaxation of the TM5-330 requirements for a 35:1 glide ratio (including a 10:1 factor of safety). The determination of the glide ratio is a function of aircraft performance. (3)

Taxiways

Length. The length should be the same as the runway. This facilitates the recovery of aircraft and allows large aircraft such as the C5 to land and turn onto taxiways with shorter turns.

Width. The width of the taxiway is controlled by the widths of the landing gear and a factor of safety to allow for maneuvering room.

Shoulders. The shoulders add to the room available for manuevering and decrease the chance of an encounter between an aircraft and some other object.

Lateral clearance zone. The lateral clearance zone on a taxiway functions much in the same manner as for the runway.

Clear area. The clear area functions in the same manner as described for the runway.

Parking Apron

Length and width. The length and width are controlled by how close the aircraft can be parked. The current control is to park no closer than to allow the jet exhaust to reach the next aircraft at a velocity of 35 miles per hour and a temperature of 100°F. Closer parking on a very short-term situation should be an acceptable risk perhaps. However, over a period of several months with maintenance personnel working around the aircraft, this could cause an unacceptable degree of risk.

<u>Transverse grade</u>. The grade should be controlled by the effects of slow speed taxiing braking requirements.

<u>Infield Clear Width</u>. The infield clear width is controlled by several factors. The first distance is that sufficient to insure that the wings of an aircraft on the runway and on the taxiway cannot collide. The second factor is to provide the pilot a "feeling" of sufficient room for the aircraft. The SELF requires an infield clear width of 180 feet. The TM5-330 recommends an infield clear width of 354 feet. Further reduction is possible. The main concern is at what point does the pilot "feel" that there is sufficient room for the aircraft.

<u>Drainage</u>. The basis for the specific drainage design are site dependent. That is that the soil composition, existing surface slopes and cover all play a major role in the final drainage design. The rational for the design of these facilities are in the TM5-330 paragraph 6-11. (5)

The one area which is open to further engineering consideration is the choice of the design storm. The current criteria is the use of a two-year storm. The TM5-330 directs the use of a one-year design storm for facilities with an expected life of six months or less.

CHAPTER III

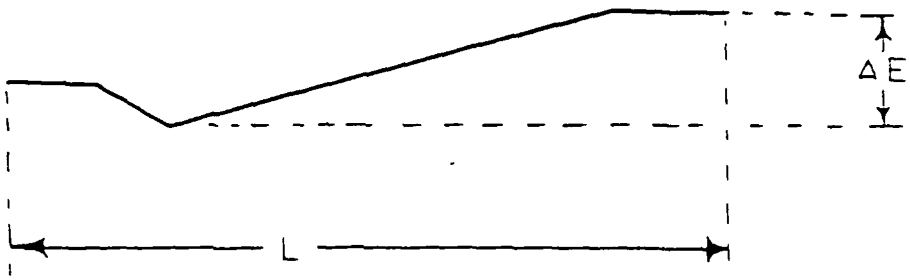
PROPOSED SELF DESIGN CRITERION

The proposed criteria are developed by reviewing and selectively reducing the factor of safety on a particular criterion. In this section, a brief discussion of how each safety factor was reviewed is provided and then a summary listing of the revised standards.

<u>Runway length</u>. In determining the runway length required, several factors are applied. These correct for elevation and temperature at the airfield site as compared to a standard. These factors are applied to the ground run distance of an aircraft to determine the required runway length for that aircraft at the selected site. For example, if a runway was required for a F4 aircraft at an elevation below 1000 feet and in an area which had a maximum temperature of less than 99° Fahrenheit, the factors would be:

Ground run	4000 feet
Elevation correction	1.0
Temperature correction	1.16
Factor of safety	1.25

which would produce a required length of 5800 feet.



Let

LG = longitudinal gradient

ΔE = maximum elevation difference

L = length of runway

$$LG = \frac{\Delta E}{L} \quad (3)$$

Figure 8. Longitudinal Gradient.

Table 3. Required Ground Run for A F-4 at Various Gradients.

Gradient %	Required Ground Run Feet	Length Increase* Feet	Percent Increase** %
0	4000	0	0
1	4223	223	5.58
2	4473	240	6.0
3	4754	281	7.0
4	5072	328	8.2
5	5435	363	9.0
6	5855	420	10.5

*This is the incremental ground run increase from the previous gradient.

**This percentage is calculated as the incremental length increase over the base length (4000).

Table 4. Required Ground Run vs Existing and Proposed Criteria.

Gradient %	Required Ground Run Feet	Existing Criteria Length Feet	Proposed Criteria Length Feet
0	4000	4000	4000
1	4223	4000	4000
2	4474	4000	4320
3	4754	not allowed	4640
4	5072	not allowed	4960
5	5435	not allowed	5280
6	5855	not allowed	5600

*Based on F4 aircraft. See Appendix A.

Transverse Gradient. The transverse gradient is controlled by comfort and wing tip clearance. Table 5 lists each aircraft expected to use the SELF and its wing tip clearance requirements in terms of a percent slope.

Table 5. Wing Tip Clearance Summary.

Aircraft Type	Maximum Clearance Slope %
F4	57
F 18	42.6
Av 8	34.9
A 6	31.3
KC 130	26.7
C141	16.1
C 5	20.0
DC 10	28.6

Note the supporting data is in Appendix B.

The minimum available clearance is for the C141 aircraft. It is proposed that the maximum transverse slope be increased to six percent. This would leave 10 percent for the C141 pilot to make final corrections. The reduction of available list might restrict the ability of a C141 to land in strong cross winds. Secondly, all aircraft will have to be reviewed to insure that this transverse slope does not place lateral loads on the landing gear structure in excess of allowable loads. This will have to conducted by aircraft manufacturers.

<u>Maximum rate of grade change</u>. The current requirements for FAA (Federal Aviation Administration) are: (8)

1.0% per 300 feet for utility airports

1.0% per 1000 feet for air carrier airports

Expressed in similar terms and including the SELF:

.33% per 100 feet for utility airports

.10% per 100 feet for air carrier airports

.165% per 100 feet for the SELF

The difference between an air carrier airport and a utility airport is that scheduled passenger aircraft do not use the utility airport. The same aircraft may use the utility field but not on a passenger schedule basis. This implies that the aircraft can withstand the higher rates of grade change.

The maximum rate of grade change will also create a void under a straight piece of matting. See Fig. 9.

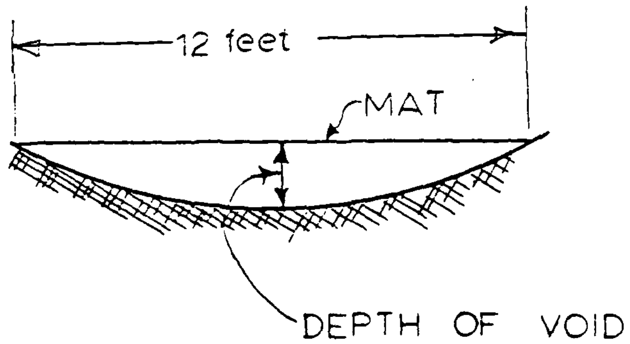


Figure 9. Smoothnesss Void.

The maximum permissible void is 1 inch to a 12-foot span. (3) The void created by various degrees of curvature (assuming a circular vertical curve) are listed in Table 6.

Table 6. Rate of Grade Change Void Requirements.

Maximum Rate Grade Change (%/100 feet)	Void (inches)
.165	.36
.22	.47
.24	.52
.26	.56

Recognizing that the difference between the void required for the vertical curve and one inch is the room available for grading error, it is recommended that the maximum rate of grade change per 100 feet be revised to 0.26% per.

<u>Lateral Safetv Zone Slopes</u>. The current lateral slope requirement is 7:1 (run to rise). This creates a large bowel for the pilot to maneuver in. The reduction of these slopes to 5:1 would still allow the pilot a lot of maneuvering room. This is controlled by the required maneuvering room and the soil stability. The soils stability consideration have been studied and found not to prevent this increase in slope. (10) The FAA

requires a 7:1 slope for large commercial airports. It seems that military aircraft should be able to maneuver in tighter quarters.

Drainage. The worst two-year design storms to be found in the world is three inches per hour. If the design storm were reduced to a one-year storm, this would reduce storm intensity to about two inches per hour. (3) The risk is that a more severe storm will occur and damage the facility. There are two basic ways in which a storm could cause damage. The first is if the airfield pavement flooded. This would prevent the use of the airfield. The water would unacceptably reduce tire friction and would present a FOD (foreign object damage) problem to the aircraft engines (if from the nose wheel, it were to spray in the engine). The second type of damage is that of erosion. The erosion of the embankment in and around the matting could cause undetectable inproperly supported matting. This matting could collapse if an aircraft were to pass over it. The maximum slopes are 6% for the matted area and 20% (these are the proposed criteria) for the infield. The infield should be treated for dust control, etc. Therefore, it is considered that these slopes are insufficient to cause an erosion problem. In any case, the life of the facility is only six months and the probability of a very extreme storm occuring in that time is relatively small.

Propose that a one-year design storm be used. Applying the above-proposed criteria to the entire list of the requirements gives the listing in Table 7.

CHAPTER IV

EVALUATION OF CONSTRUCTION EFFORT USING PROPOSED CRITERIA

In order to evaluate the construction effort reduction achieved through the relaxation of the design criterion, a model of the SELF was developed. The model is based upon the criteria which exist and then a worst case situation is developed for each desired criterion and the construction effort for the model and the revised criterion is calculated. The model itself is not all that realistic as it assumed a plane which is then titled or twisted to evaluate each case. The results of these calculations, however, provide an indication of the magnitude of change caused by a parameter. The results are not exact estimates of any actual condition but allow for the effect of a single parameter to be observed

The layout design of the standard for these calculations consists of a runway and parallel taxiway which conform to the existing SELF design standards. See Fig. 10 for the exact layout. In developing the standard elevations where choosing to balance cut and fill, no allowance for swelling or shrinkage of the soil was included. In order to estimate the mandays of construction effort,

Table 7. Proposed SELF Criteria

Runway	
Length	Variable +
Width	96 feet
Gradients	
Longitudinal	0 to 4% +
(add 8% length for each % gradient over 1%)*	
Transverse	0.5 - 6.0% +
Maximum rate of grade change per 200 ft	0.26% +
Shoulders	
Length	Same as runway
Width	20 feet
Transverse grade	0.5 - 6.0% +
Clear Area	
Width	35 feet
Transverse gradient	1.5 - 6.0% +
Overrun	
Length	500 feet
Width	96 to 288 feet
Lateral Safety Zone	
Slope	5 to 1 +
Runway Approach Zone	
Ratio	15:1
Length	15,000 feet
Taxiway	
Length	Same as runway
Width	78 feet
Gradients	
Longitudinal	0.0 to 4.0%
Transverse	0.5 to 6.0% +
Shoulders	
Width	20 feet
Length	Same as runway
Transverse Grade	0.0 to 6.0% +
Lateral Clearance Zone	180 feet
Clear Area Width	65 feet
Maximum Transverse Grade	6% +
Parking Apron	
Length	2,000 feet
Width	432 feet
Shoulders	
Width	20 feet
Transverse Grade	1.5 to 6.0% +
Lateral Clearance Zone	65 feet
Drainage	1-year design storm

+Represents changed criterion.

*The first 500 feet have to have a slope of 0.0%.

CHAPTER IV

EVALUATION OF CONSTRUCTION EFFORT USING PROPOSED CRITERIA

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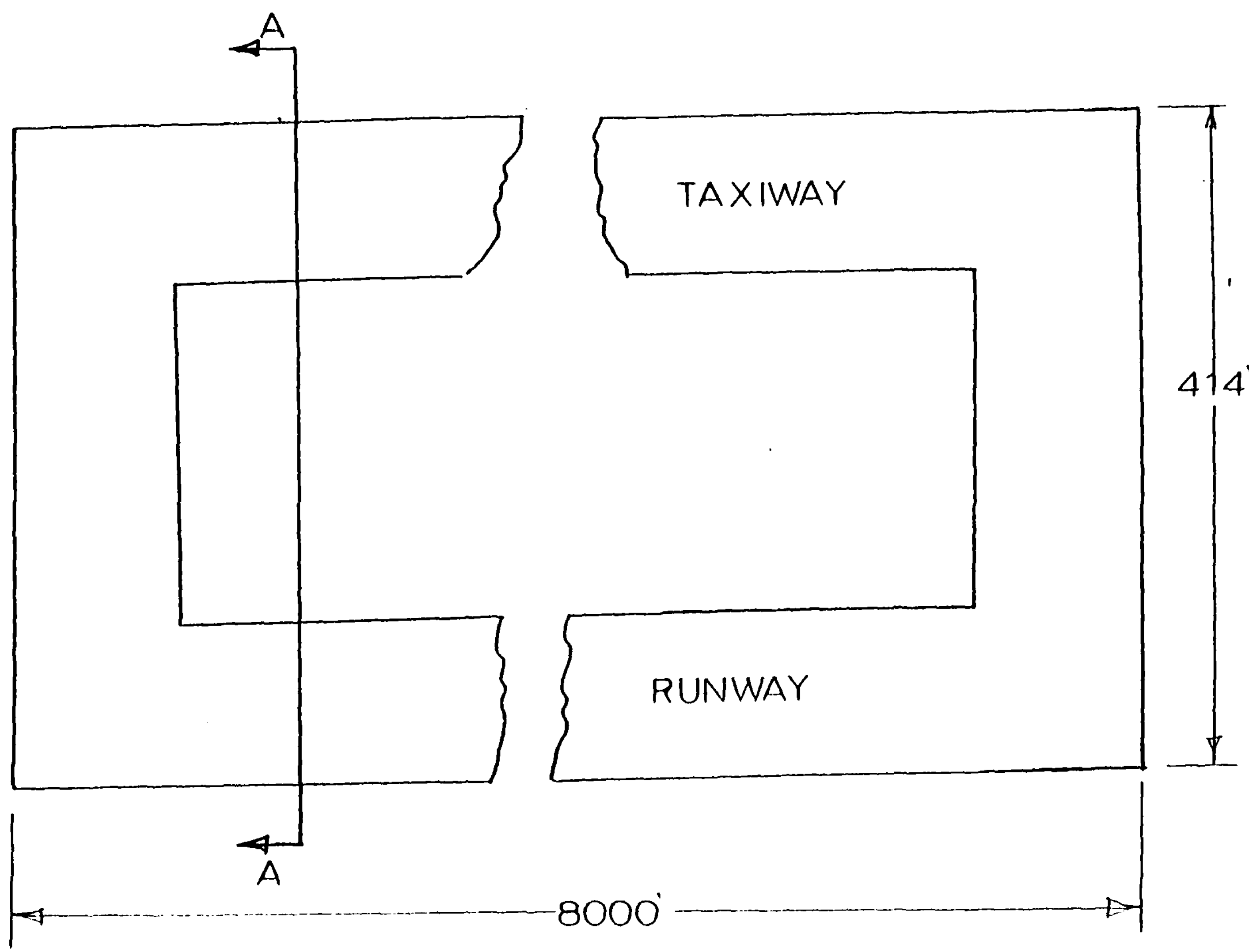

Figure 10. Model SELF.

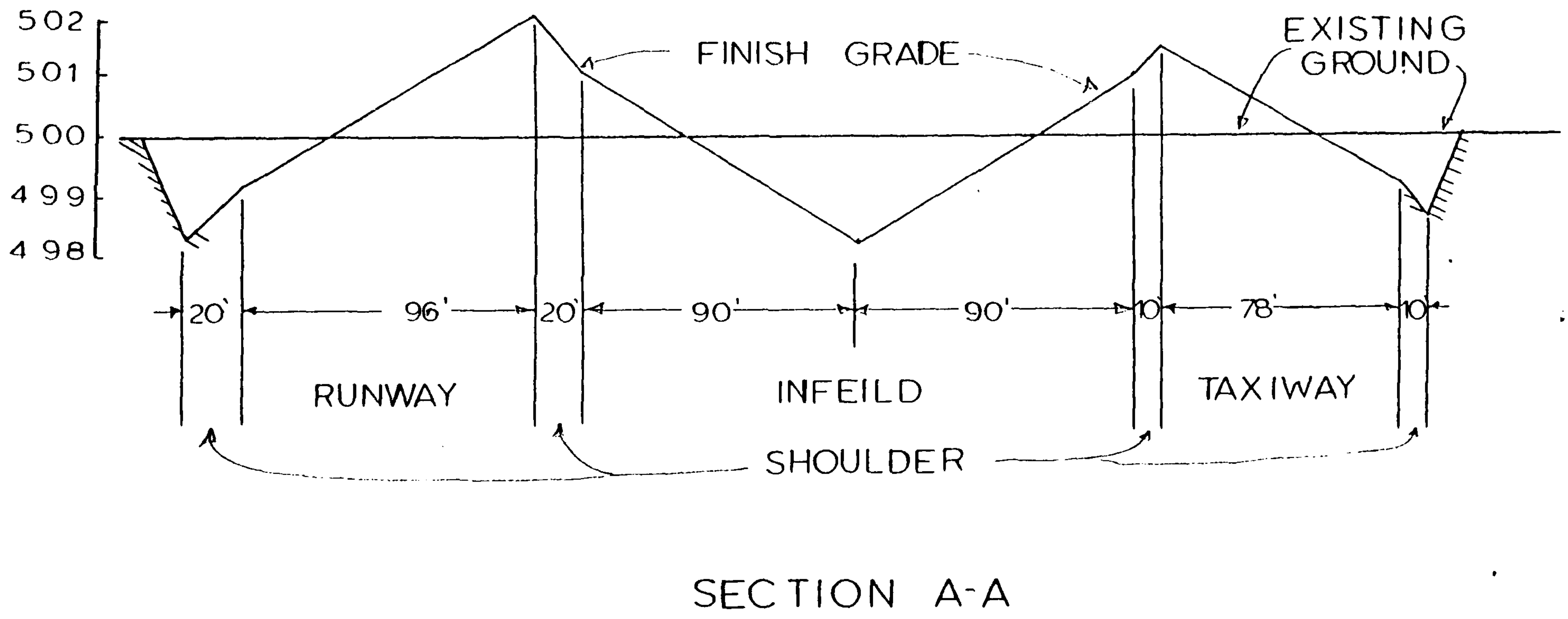

Figure 10. (continued)

production quantities were required for various types of functions. These production rates are based upon the SEABEE Estimating Handbook. (7) (See Appendix D for the ones chosen and their application.) These factors are in terms of mandays of effort to accomplish a project. The manday is defined as eight hours per workday. If this were to be expressed in manhours of effort (simply by multiplying by eight) and then have manpower assigned, it would be expressed in the same fashion as other contingency plans. The efforts of the paper will not include the assignment of crews and attempts to evaluate elapsed times.

Having the standard layout and production rates for each type of work, then the problem of estimating the quantities of work required to construct the model had to be solved. A computer program was developed. The exact use and explanation of this program is in Appendix C. Appendix D is a sample calculation of the construction effort using the standard SELF displayed in Fig. 10.

As is apparent from Appendix D, only the construction effort involved in the earthwork and drainage installation are evaluated although there are many more items of work involved in the actual construction of the finished facility. Items such as placing the matting, the matting anchoring system, lighting system, arresting gear, are not considered in these calculations of construction effort. The effort

involved either remains constant or is a linear function of the variation in length. In either case, these efforts are beyond the scope of this study. In view of the above, if a percentage of efforts is cited as to be saved, it only is using the earthwork and site preparation effort as its based.

Runway length. The runway length can be reduced if the construction is at lower elevations. By varying the elevation correction factor and using the ground run of a F-4 aircraft, the required length of runway was calculated. Then the construction effort was estimated in accordance with Appendixes C and D to develop Table 8.

Table 8. SELF Construction Effort at Various Elevations.

Elevation Feet	Runway Length Feet	Construction Effort Mandays
less than 1000	5800	1667
1000-2000	6400	1860
2000-3000	7000	2035
3000-4000	8000	2322

Note: This assumes a temperature of less than 99° and a factor of safety of 1.25.

The relaxation of the minimum length of runway from 8000 feet could result in a savings of 28% in the site preparation effort.

Runway longitudinal gradient. The maximum longitudinal gradient can be increased from 2% to 4% if in doing so the runway length is increased sufficiently to allow an aircraft to achieve flight velocity. The model for this evaluation was tilted along the longitudinal axis of the runway. The resulting slope can increase up to 2% before there is any adjustment required. Then under the current criteria, the slope of the runway remains constant and the amount of effort required increases as the gradient increases. In balancing the cut and fill for this application, the cut end of the runway was extended at an upward slope of 15 to 1 (run to rise) slope until the interception with existing ground. This gentle slope is required to allow for the approach glide angle to that end of the runway. The toe of the fill end was constructed at 7 to 1, the current criterion. These end conditions added a large amount of earth work to be accomplished. Figure 11 shows the general shape of the existing criteria model.

The effect of parameter only pertains when the differences in elevation of a proposed site are quite large. (A 5% slope for an 8000-foot runway would require an elevation difference of 400 feet.) Because of the extreme amount of manpower to be expended in the construction of a facility on such a site, currently it would not be seriously considered. Therefore, the effect of this

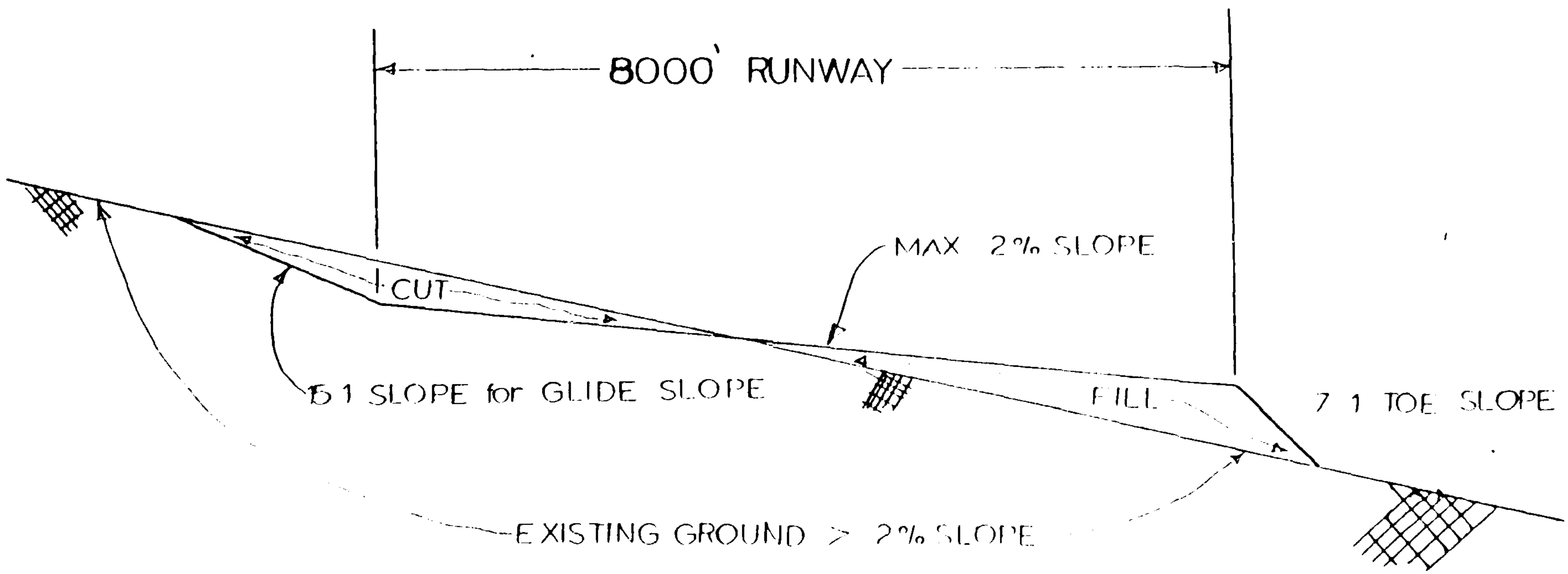

Figure 11. Longitudinal Gradient Model of SELF.

relaxation in criteria is to allow more sites to be available for evaluation. The construction effort as found by the model under old and new criteria are displayed in Table 9. As can easily be seen, if a requirement existed to construct a SELF on a site with a grade of 4% along the required runway alignment, the task would be almost impossible. However, with the relaxed criteria, the task is reasonable.

Transverse gradient. To evaluate the effect of the transverse gradient (surface sloped from left to right) on the construction effort required the standard SELF was built on a sloped existing ground. The standard SELF's cross section was changed to follow the transverse ground slope as closely as possible using the existing criteria. The final elevation of centerline was adjusted so as to balance the cut and fill requirements. Figure 12 shows the cross section used. Then, in the same manner, a second model was established for the proposed criteria. (See Figure 13.) For both models, a slight ditch was created on the uphill side to insure that no water flowed across the airfield pavement. The rather gentle slopes required by the airfield make the width of the work area quite wide and creates a great deal more earthwork than might be expected. The following results were calculated from the model.

Table 9. SELF Construction Efforts for Various Longitudinal Gradients.

Ground Slope %	Current Criteria: Runway Length Feet	Current Criteria: Centerline Slope %	Current Criteria: Construction Effort Mandays	Proposed Criteria: Runway Length Feet	Proposed Criteria: Centerline Slope %	Proposed Criteria: Construction Effort Mandays
0	8000	0	2322	8000	0	2322
1	8000	1	2322	8000	1	2322
2	8000	2	2322	8000	2	2322
3	8000	2	7790	8000	3	2517
4	8000	2	66796	9400	4	2713
5	8000	2	147751	10100	5*	2922

*Note: Not considered acceptable by current or proposed criteria. For information only.

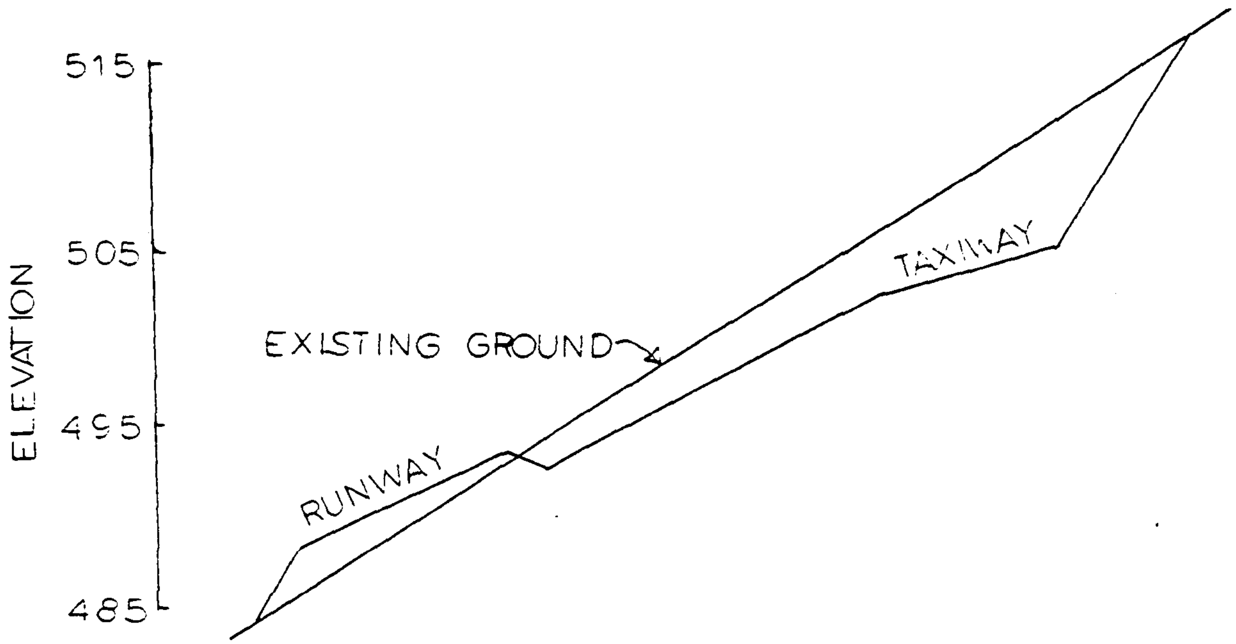

Figure 12. Current Transverse Gradient Criteria Model.

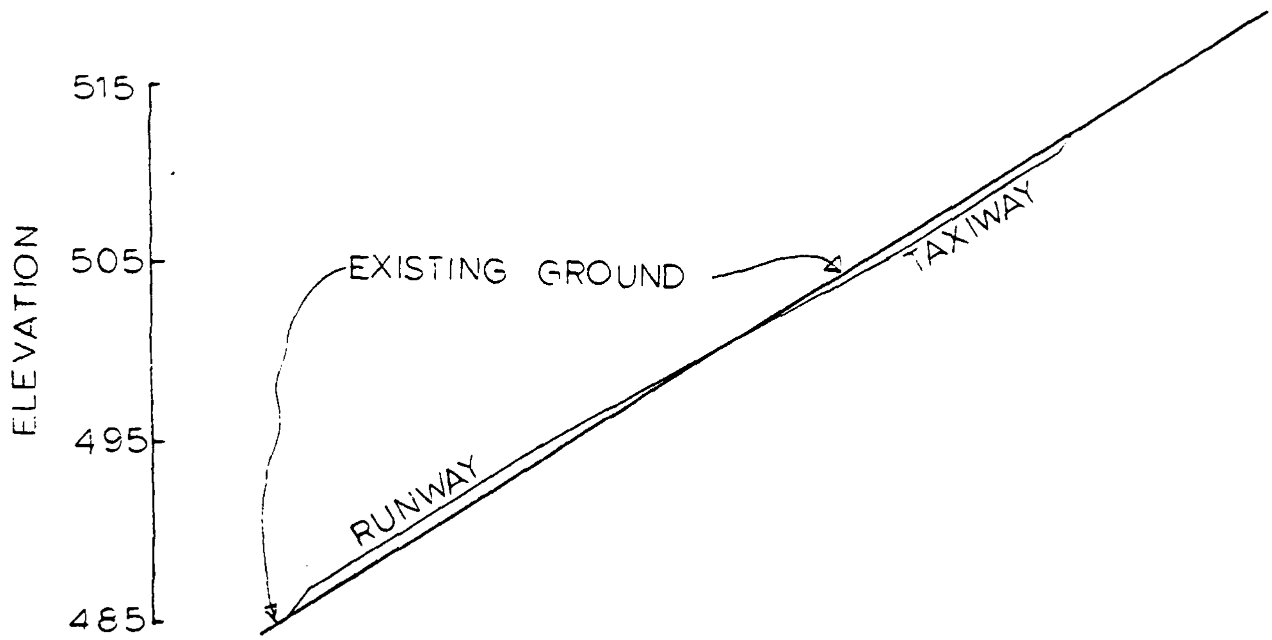

Figure 13. Proposed Tr.nsverse Gradient Criteria Model.

Type	Mandays of Effort
Current	14,119
Proposed	2,936

The acceptance of a 6% cross slope can save a considerable amount of construction effort.

Maximum rate of grade change. To evaluate this parameter, the standard SELF was changed to create a single vertical curve at the center of the runway. The finish elevation was kept at the same elevation as the standard. This caused the vertical curve to be built on a fill. The quantity of fill varies inversely with the percent of grade change per 100 feet. That is, the largest rate of change requires the smallest amount of fill, and therefore, the least construction effort. Figure 14 shows the vertical curve created in the model for these evaluations. The construction effort was then calculated for each rate of grade change and for 2, 4, and 6% grade change. The results are shown in Fig. 15. The maximum rate of grade change does not have a significant effect until the grade change is 4% or more.

Drainage. The worst intensity of a two-year storm for any location in the world is three inches per hour. (3) If a design storm of one year were chosen, that would reduce this design intensity to approximately two inches per hour. (3) Using these intensity values, the

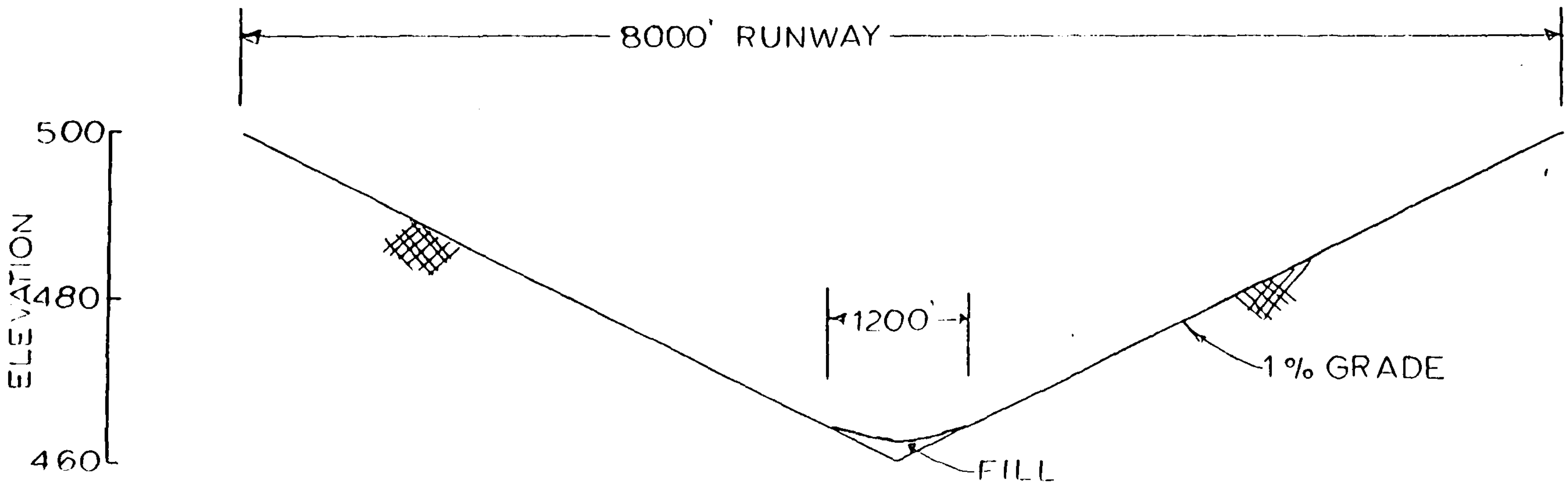

Figure 14. Maximum Rate of Grade Change Model.

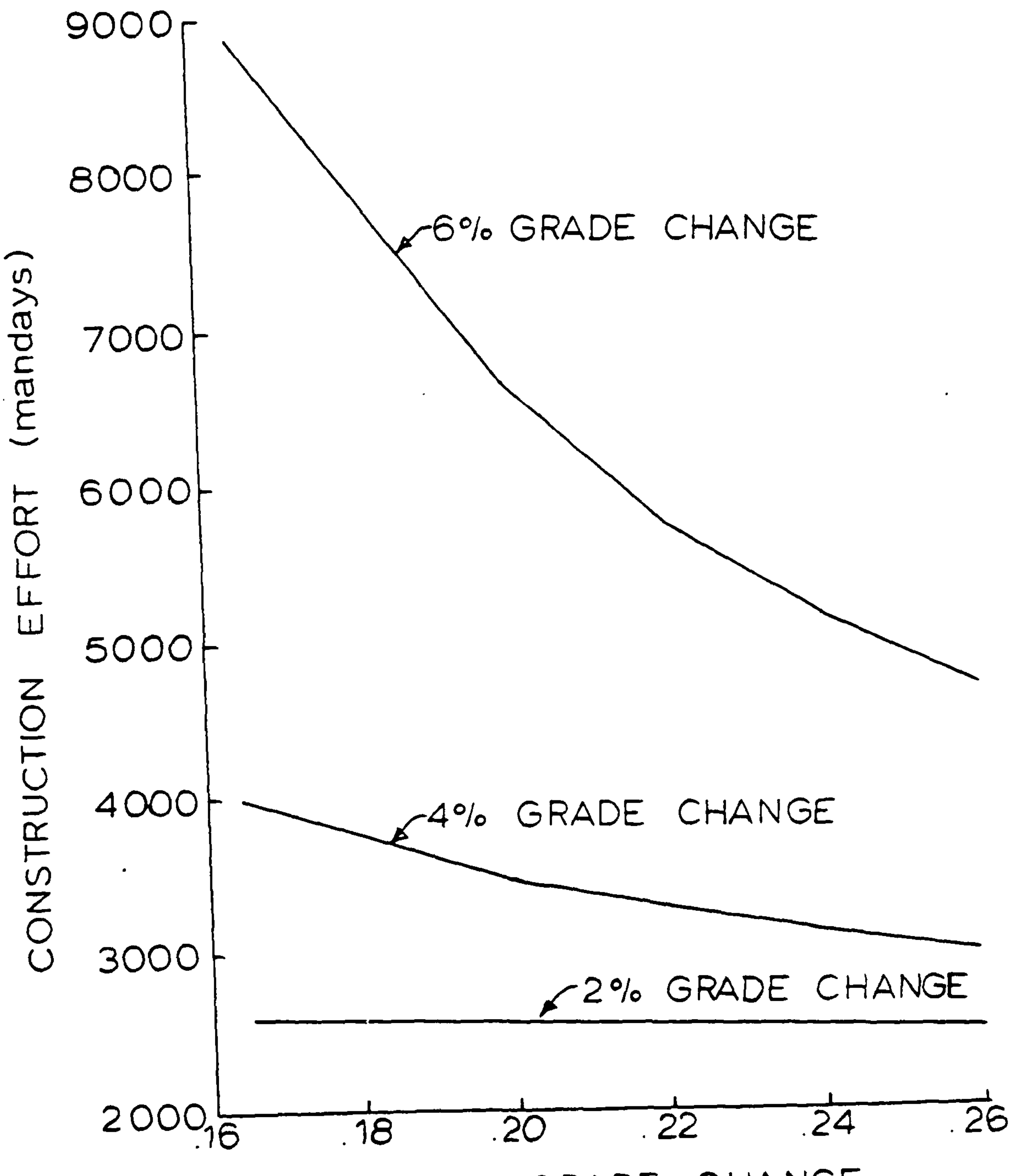

Figure 15. Construction Effort for Various Maximum Grade Change.

construction effort for drainage facilities were then calculated. The results of these and other intensities are displayed as a graph in Fig. 16. It should be pointed out that the immediate removal of all water is not required as a functional retention pound is created in the infield area. Water could pound here as long as it did not become deep enough to actually stand on the airfield pavement. Therefore, at least in the Standard SELF used here, the reduction of the design storm has little effect on the operations of the facility. The effects of the water pounding in the infield have been investigated and found not to be significant. (10)

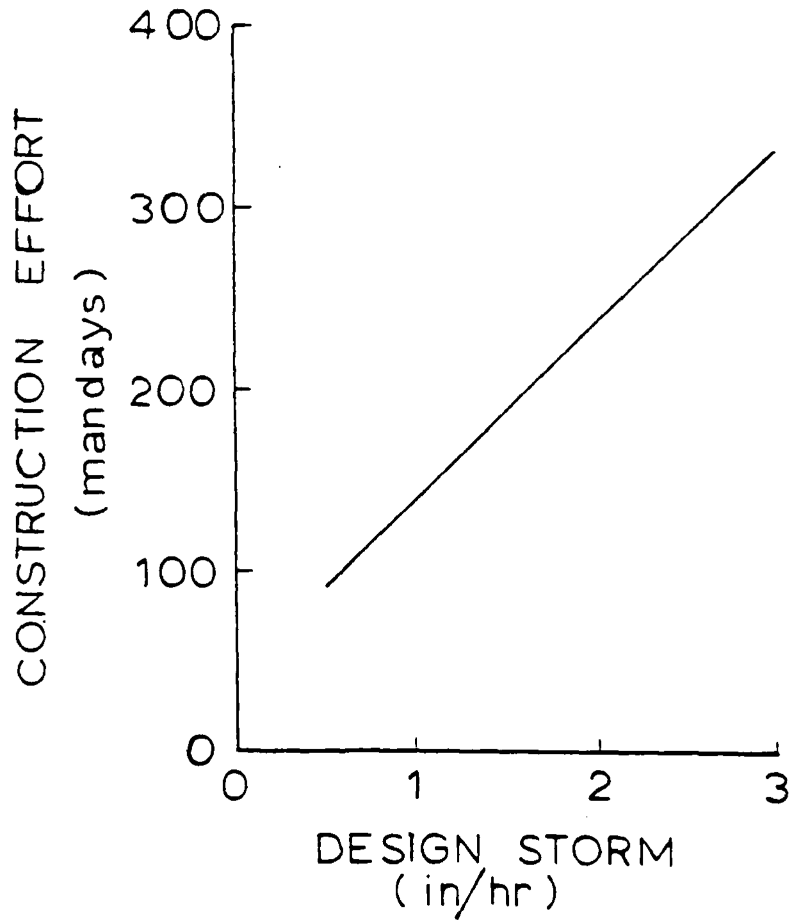

Figure 16. SELF Drainage Construction Effort for Various Storm Intensities.

CHAPTER V

CONCLUSIONS

The construction effort required to affect the current AOA contingency facilities can be reduced through the review of controlling criteria. The arena which will yield the greatest reduction in construction effort is that of site preparation. The parameters with site preparation which have the greatest benefit are those which restrict the close approximation of existing ground conditions in the finished product.

In the specific instance of the SELF, the parameters which have the greatest benefit are the longitudinal gradient and the transverse gradient. Though the approximation of construction effort through a model SELF based on a flat plane are not realistic, the relative savings reflected are of value in the evaluation of the effects of a given parameter.

The SELF has several additional areas which require further investigation.

--The increasing of the deviation tolerance would perhaps greatly reduce the construction effort. Currently, approximately one-third of the model SELF's construction

effort is for final grading and compaction. The effects on reduction in compaction effort have been studied. (10)

--The factors of safety within the runway length estimate for the elevation and the temperature correction. The TM5-330 does not reflect a factor of safety in these corrections; however, if the physical principles were evaluated, factors of safety would most likely come to light.

--Further, the effect of multiparameter relaxation have not been investigated either from the construction effort saved or the possible compounding effects on the operation of aircraft.

The stated life of six months is difficult to accept. The current cost of AM-2 matting is approximately $20 per square foot. At this price, the matting alone for a SELF would cost approximately $50 million. Additionally, despite the term expeditionary in its title, SELF is not very mobile. Therefore, consider the ability to improve the constructed SELF to higher standards an item worthy of study. Criteria such as toe slopes and length are excellent candidates for later renovation to more permanent standards. The construction work for these improvements can be conducted while the SELf is in operation.

Other criteria are less adjustable or less convenient to correct after the SELF has been placed in service. The installation of additional infield drainage structures and

flattening of a transverse slope are examples. These items can be reconstructed, but they will require that the SELF or at least some portion of it be removed from service while the correction is made.

The remaining individual item within the AOA have far less constraint than does the SELF. However, facilities which merit some attention are ammunition developments, fuel farm berms, and temporary port facilities.

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APPENDIX A

AIRCRAFT REQUIRED GROUND RUN

The purpose of this appendix is to evaluate the required aircraft ground run caused by an increase of the effective grade of the runway.

Let

F_e = force of aircraft engines

F_r = retarding force due to grade

F_n = net force available for accelerating the aircraft

V = required take off velocity

M = mass of aircraft

x = required ground run

A_n = net acceleration

A_r = retarding acceleration due to grade

A_e = normal acceleration produced by engines

G = acceleration due to gravity

g = runway gradient

For a level runway, there is no F_r.

$$F_n = F_e$$

and

$$F_e = MA_n$$

Also,

$$V^2 = 2A_n x$$

Therefore,

$$(220 \text{ ft/sec}^2)^2 = 2A_n(4000)$$

$$A_n = 6.05 \text{ ft/sec}^2$$

based on an F4 aircraft. Flight speed is 150 miles per hour and minimum required ground roll is 4000 feet.

For a runway with a gradient:

$$F_n = F_e - F_r$$

but

$$F_n = MA_n$$

$$F_e = MA_e$$

$$F_r = MA_r$$

By substitution

$$A_n = A_e - A_r$$

from above,

$$A_e = 6.05 \text{ ft/sec}^2$$

Applying statics to the force of gravity and breaking G into two component forces, one normal to and one parallel to, to the runway surface

$$A_r = G \sin g$$

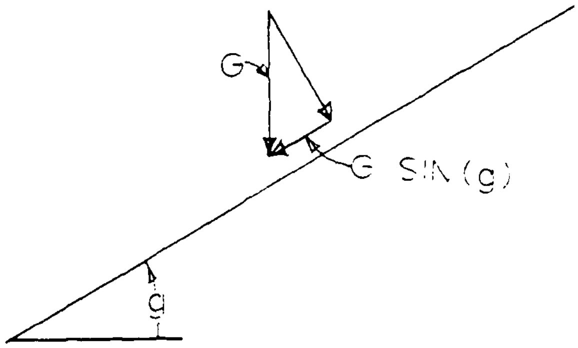


Figure 17. Retarding Force for Runway Gradient.

At 1% grade,

$$A_n = 6.05 \text{ ft/sec}^2 - (32.17 \text{ ft/sec}^2(\sin g))$$

$$g = .57°$$

$$A_n = 5.73 \text{ ft/sec}^2$$

Therefore,

$$x = 4223 \text{ feet}$$

APPENDIX B

WING TIP CLEARANCE SLOPE

The purpose of this appendix is to display the data used to determine the maximum slope for wing tip clearance.

Aircraft Type	Wing Span Feet*	Gear Span Feet*	Wing Tip Feet*	Maximum Slope *
F-4	38.625	17.875	6.0	57
F-18	40.21	10.21	6.44	42.6
AV-8	30.29	14.4	2.78	34.9
A-6	53.0	10.875	6.6	31.3
KC-130	132.583	14.25	15.8	26.7
C-141	159.916	20.66	11.0	16.1
C-5	222.71	37.458	18.58	20.06
DC-10	155.33	35.0	17.21	28.6

*Data from References 6 and 9.

The wing tip clearance slope is calculated in the following formula:

$$\text{Maximum slope} = \frac{\text{wing tip height}}{\frac{\text{wing span-gear span}}{2}} \times 100$$

APPENDIX C

USERS' MANUAL FOR EARTHWORK PROGRAM

Acknowledgment. My thanks is given to Mr. Joe Cuccu who developed the basic algorithm for this program in his program FIRD. (13) Though the basic algorithm is his, the exact form of the program has been considerably changed.

This program is designed to determine a cross section profile of a runway and calculate the quantities of earthwork to construct that profile. The data which is displayed is sufficient for complete analysis of the finished profiles and estimation of the mandays of construction effort. The input data required is the description of the final cross section, final desired grade between stations and a description of the existing ground. The conceptual flow chart is shown in Fig. 18.

The output consists of several sections. First is a secton entitled Existing Conditions. The columns are labeled STA NO, LS ELEV, CL ELEV, RS ELEV, EXISTING SLOPE and PROPOSED SLOPE (the station number, existing left side elevation, existing centerline elevation, the existing right side elevation, the existing slope, and the desired final slope, respectively). The existing slope is

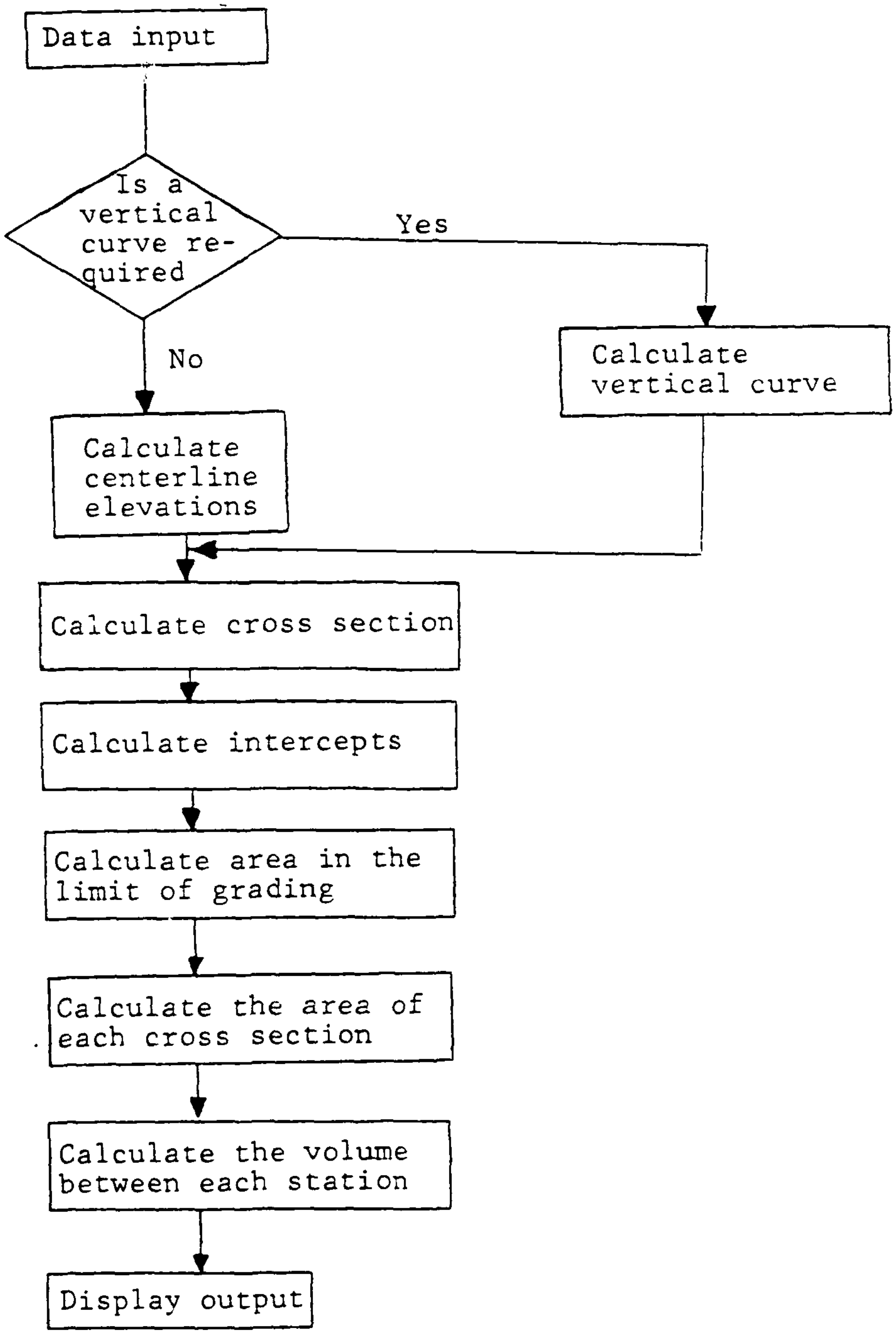


Figure 18. Flow Chart of Earthwork Program.

the slope between adjacent centerline elevations from the preceding station to this station.

The next section is entitled CROSS SECTION. First, a repeat of the data entered appears in the form of lines labeled SLOPE and WIDTHS. The values represent the slope and width provided in the data set to calculate the finish elevations relative to the center line (see Figure 19). Then listed is an elevation for each of nine points in the cross section. (See sample profile in Fig. 19 for exact locations.)

Next is a section entitled INTERSECTION POINTS which lists the grade, elevation, distance for the left and right side intersection of the toe slope and existing ground. Grade is expressed as a single number (i.e., 7) which stands for a 7:1 (run to rise) slope.

Next is a single number labeled AREA WITHIN LIMITS OF GRADING. This value represents the area of a horizontal plane whose area will cover the limits of the earthwork.

The last section is entitled VOLUMES. All volumes are calculated via the average end area method. The columns are labeled and self explanatory except the one entitled TOTAL MOVED. The total moved represents the volume of earth to be excavated between stations. This volume is the summation of the areas which are below existing grade and above final grade. (See Fig. 20.) This volume may be in excess of the stations requirements

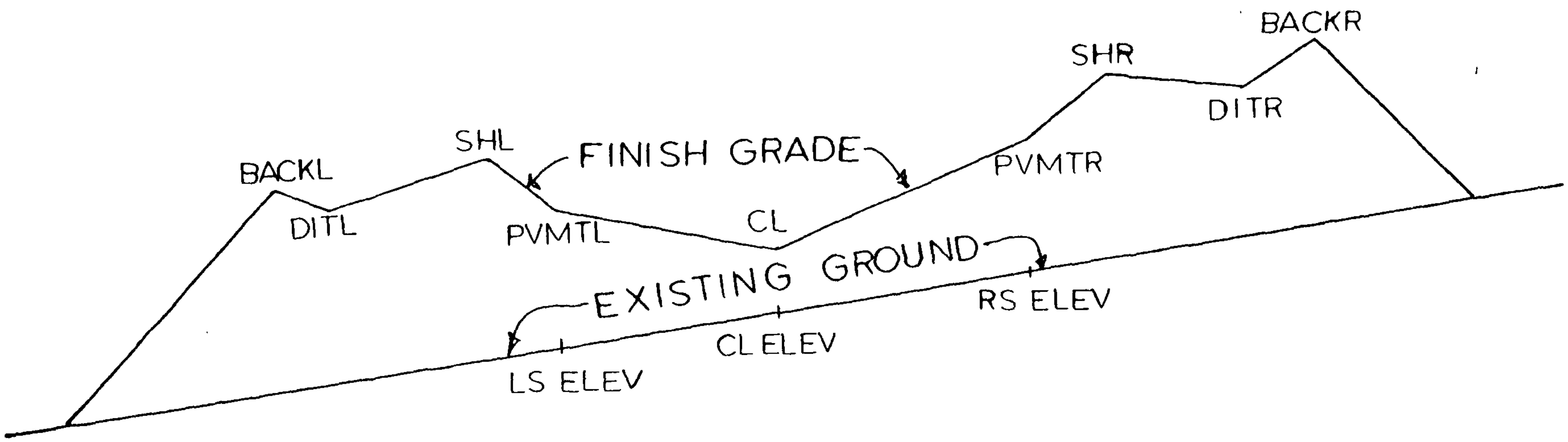


Figure 19. Variable Definitions for Earthwork Program.

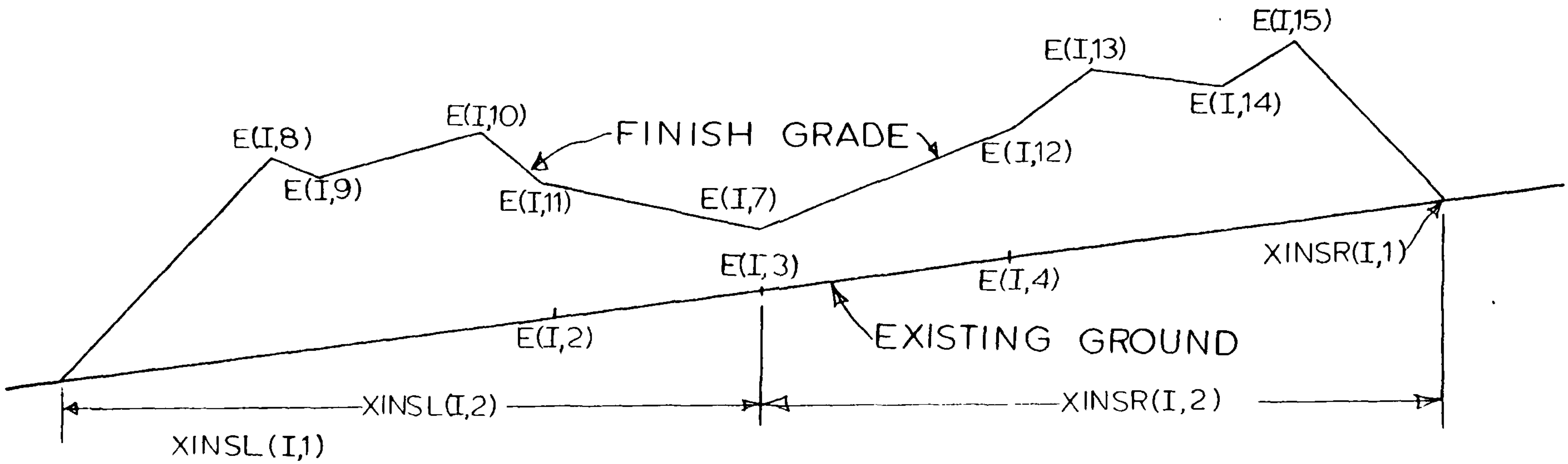
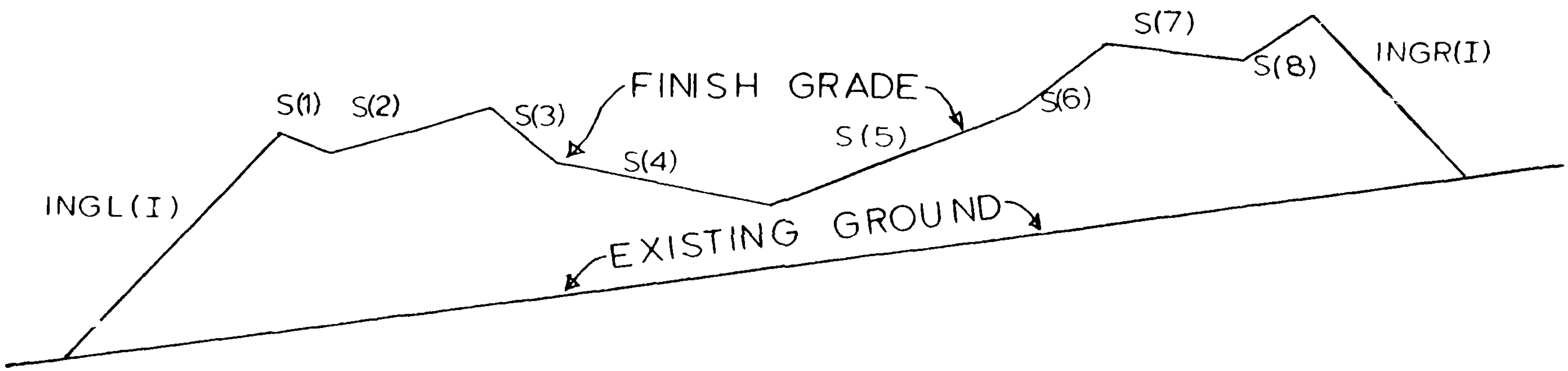


Figure 19. (continued)



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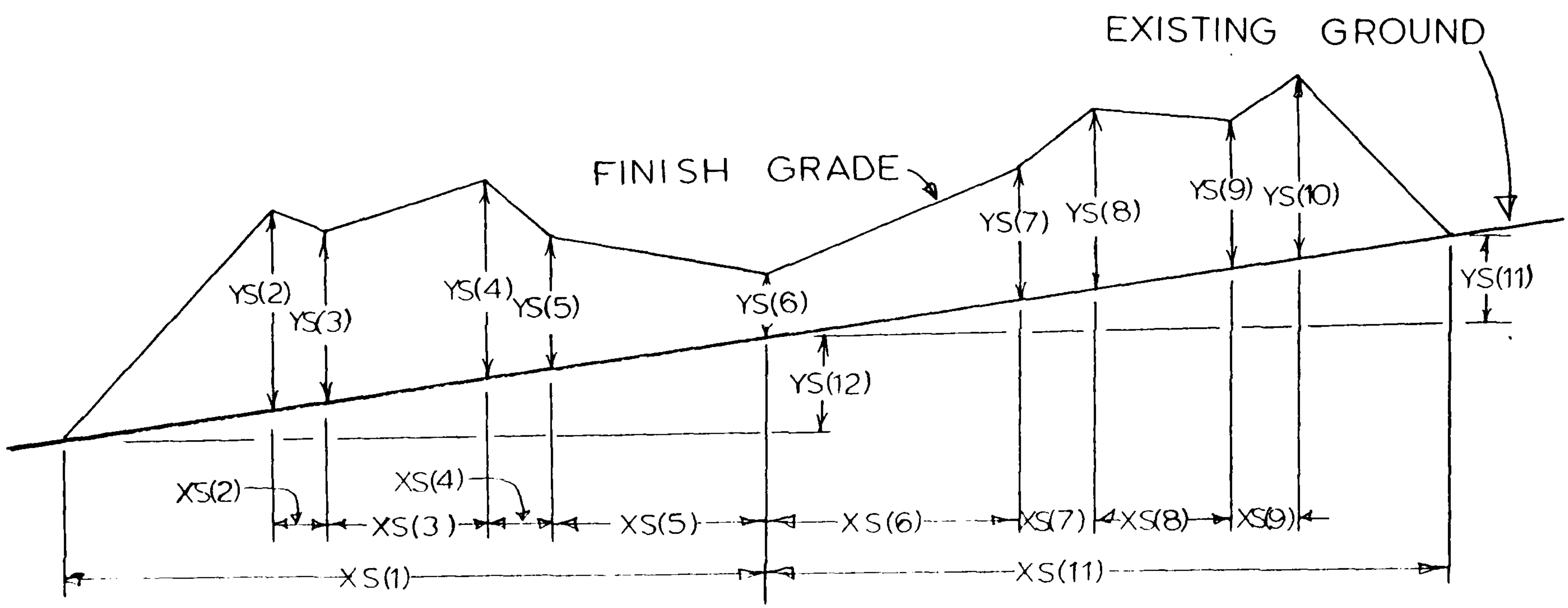

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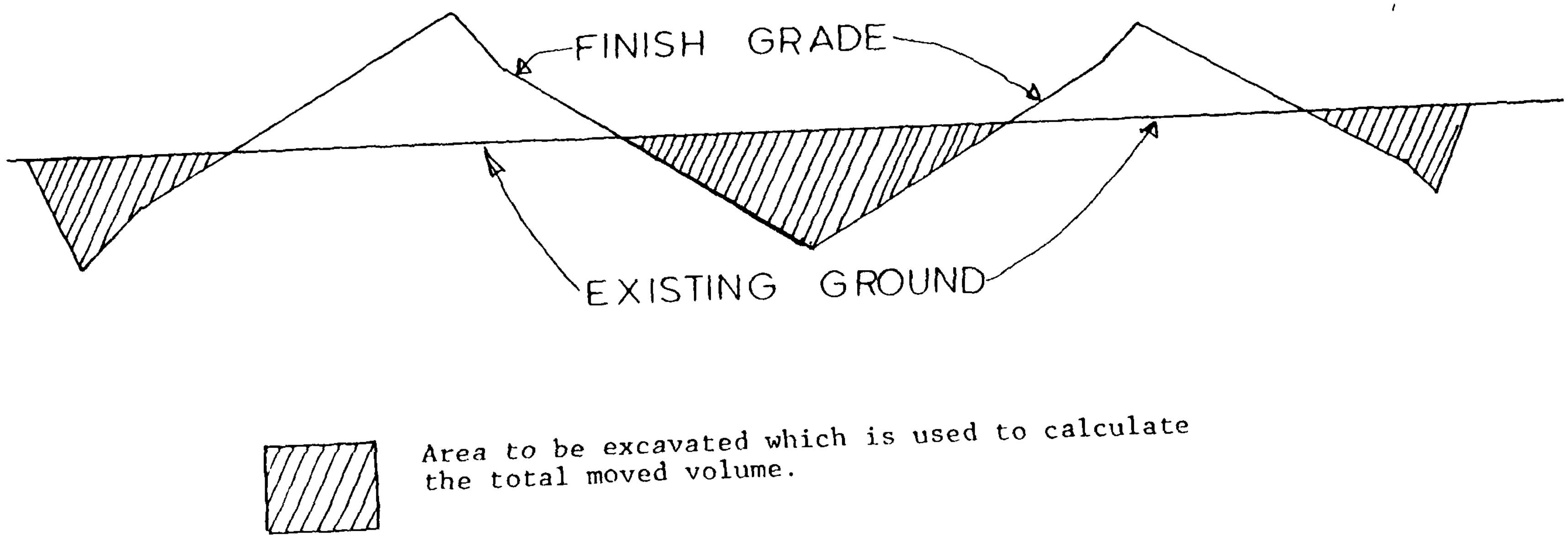

Figure 20. Definition of Total Moved.

or may be required within the station to build the crown portion of the cross section. If the station is a "pure cut" the TOTAL MOVED will equal the volume to be cut at that station. If the station is a "pure fill" the TOTAL MOVED value will be 0.0. If the station is neither "pure cut or pure fill" then the value of the VOLUME BETWEEN STATIONS and TOTAL MOVED are different (and total moved not equal to 0.0), then the TOTAL MOVED is the total volume excavated and the VOLUME BETWEEN STATIONS is the net volume to that section be it a cut or fill value. The value labeled TOTAL VOLUME TO BE MOVED is the sum of the TOTAL MOVED column. To determine the total amount of earthwork, the value of the CUMULATIVE VOLUME and TOTAL VOLUME TO BE MOVED must be summed. There are some restrictions to the program:

a) The program will use only one cross section in a given set of data. However, the program will run multiple sets of data in one run.

b) The program does not allow for the evaluation of end conditions. It assumes a vertical plane.

c) Only eight (8) different slopes can be included in one cross section.

e) The maximum number of stations per data set is 50.

To use. First a data set must be entered as per Fig. 21. Next, log on Cyber Account CE113AA. Enter the following commands:

OLD,RB

GET, name of your data file

RB, name of your data file, name of desired output file

LINK, name of output file, GTCE

This will deliver the output to the COPE Room printer.

Figure 22 is a sample of the output. Figure 23 is a listing of the source code for the program (File RE on Account CE113AA), and Table 10 is a listing of the variables and their definitions in the program.

Line	
1	Number of data sets this run.
2	Number of stations this data set (maximum 50).
3	Station number, existing elevations (three) left side, centerline, right side, finish grade this station to the next as a percent, the toe slope (two) left, right as a single number (7 to represent 7:1 run to rise). Repeat line 3 for each station.
4	Finish elevation desired at first station.
5	Slopes in the cross section as decimal values eight required (S(1-8)). See Fig. 18-3. Positive is upward moving out from the centerline.
6	Widths of the eight sections in the cross section (XS(2-9)). See Fig. 18-4.
7	Maximum rate of grade change per 100 feet as a decimal. Repeat lines 2 through 7 for each data set. See Page 76 for an actual data set.

Figure 21. Data Set.

```
1
29
0.00,500.00,500.00,500.00,0,7,7
10.00,500.00,500.00,500.00,0,7,7
20.00,500.00,500.00,500.00,0,7,7
30.00,500.00,500.00,500.00,0,7,7
31.00,500.00,500.00,500.00,0,7,7
32.00,500.00,500.00,500.00,0,7,7
33.00,500.00,500.00,500.00,0,7,7
34.00,500.00,500.00,500.00,0,7,7
35.00,500.00,500.00,500.00,0,7,7
36.00,500.00,500.00,500.00,0,7,7
37.00,500.00,500.00,500.00,0,7,7
38.00,500.00,500.00,500.00,0,7,7
39.00,500.00,500.00,500.00,0,7,7
40.00,500.00,500.00,500.00,0,7,7
41.00,500.00,500.00,500.00,0,7,7
42.00,500.00,500.00,500.00,0,7,7
43.00,500.00,500.00,500.00,0,7,7
44.00,500.00,500.00,500.00,0,7,7
45.00,500.00,500.00,500.00,0,7,7
46.00,500.00,500.00,500.00,0,7,7
47.00,500.00,500.00,500.00,0,7,7
48.00,500.00,500.00,500.00,0,7,7
49.00,500.00,500.00,500.00,0,7,7
50.00,500.00,500.00,500.00,0,7,7
58.00,500.00,500.00,500.00,0,7,7
60.00,500.00,500.00,500.00,0,7,7
64.00,500.00,500.00,500.00,0,7,7
70.00,500.00,500.00,500.00,0,7,7
80.00,500.00,500.00,500.00,0,7,7
498.2957727
-0.05,-0.03,0.05,0.03,0.03,0.05,-0.03,-0.05
20,96,20,90,90,10,78,10
0.165
```

Figure 21. (continued)

```
THIS PROGRAM WILL CALCULATE THE ELEVATIONS OF A FINISH
GRADE AND THE VOLUMES OF THE CUT OR FILLS REQUIRED TO
ACHIEVE THAT GRADE.  THE EXISTING ELEVATIONS,DESIRED SLOPE
BETWEEN STATIONS,AND THE DESIRED CROSS SECTION SLOPES AND
WIDTHS MUST BE PROVIDED.
```

Figure 22. Sample Output.

EXISTING CONDITIONS

STA NO	LS ELEV	CL ELEV	RS ELEV	EXISTING SLOPE	PROPOSED SLOPE
0.000	494.600	500.000	505.400	0.000	0.000
10.000	494.600	500.000	505.400	0.000	0.000
20.000	494.600	500.000	505.400	0.000	0.000
30.000	494.600	500.000	505.400	0.000	0.000
31.000	494.600	500.000	505.400	0.000	0.000
32.000	494.600	500.000	505.400	0.000	0.000
33.000	494.600	500.000	505.400	0.000	0.000
34.000	494.600	500.000	505.400	0.000	0.000
35.000	494.600	500.000	505.400	0.000	0.000
36.000	494.600	500.000	505.400	0.000	0.000
37.000	494.600	500.000	505.400	0.000	0.000
38.000	494.600	500.000	505.400	0.000	0.000
39.000	494.600	500.000	505.400	0.000	0.000
40.000	494.600	500.000	505.400	0.000	0.000
41.000	494.600	500.000	505.400	0.000	0.000
42.000	494.600	500.000	505.400	0.000	0.000
43.000	494.600	500.000	505.400	0.000	0.000
44.000	494.600	500.000	505.400	0.000	0.000
45.000	494.600	500.000	505.400	0.000	0.000
46.000	494.600	500.000	505.400	0.000	0.000
47.000	494.600	500.000	505.400	0.000	0.000
48.000	494.600	500.000	505.400	0.000	0.000
49.000	494.600	500.000	506.300	0.000	0.000
50.000	494.600	500.000	505.400	0.000	0.000
58.000	494.600	500.000	505.400	0.000	0.000
60.000	494.600	500.000	505.400	0.000	0.000
64.000	494.600	500.000	505.400	0.000	0.000
70.000	494.600	500.000	505.400	0.000	0.000
80.000	494.600	500.000	505.400	0.000	0.000

******************************** CROSS SECTION ********************************

STA	BACKL		DITL		SHL		PVMTL		CL
SLOPE		-.060		-.060		-.040		-.060	
WIDTHS		20.0		96.0		20.0		90.0	
0.000	483.290		484.490		490.250		491.050		496.450
10.000	483.290		484.490		490.250		491.050		496.450
20.000	483.290		484.490		490.250		491.050		496.450
30.000	483.290		484.490		490.250		491.050		496.450
31.000	483.290		484.490		490.250		491.050		496.450
32.000	483.290		484.490		490.250		491.050		496.450
33.000	483.290		484.490		490.250		491.050		496.450
34.000	483.290		484.490		490.250		491.050		496.450
35.000	483.290		484.490		490.250		491.050		496.450
36.000	483.290		484.490		490.250		491.050		496.450
37.000	483.290		484.490		490.250		491.050		496.450
38.000	483.290		484.490		490.250		491.050		496.450
39.000	483.290		484.490		490.250		491.050		496.450
40.000	483.290		484.490		490.250		491.050		496.450
41.000	483.290		484.490		490.250		491.050		496.450
42.000	483.290		484.490		490.250		491.050		496.450
43.000	483.290		484.490		490.250		491.050		496.450
44.000	483.290		484.490		490.250		491.050		496.450
45.000	483.290		484.490		490.250		491.050		496.450
46.000	483.290		484.490		490.250		491.050		496.450
47.000	483.290		484.490		490.250		491.050		496.450
48.000	483.290		484.490		490.250		491.050		496.450
49.000	483.290		484.490		490.250		491.050		496.450

Figure 22. (coninued)

```
  50.000         483.290         484.490         490.250         491.050         496.450
  58.000         483.290         484.490         490.250         491.050         496.450
  60.000         483.290         484.490         490.250         491.050         496.450
  64.000         483.290         484.490         490.250         491.050         496.450
  70.000         483.290         484.490         490.250         491.050         496.450
  80.000         483.290         484.490         490.250         491.050         496.450

STA              PVMTR           SHR             DITR            BACKR

SLOPE     .060            .060            .060            .040
WIDTHS    90.0            10.0            78.0            10.0
   0.000         501.850         502.450         507.130         507.530
  10.000         501.850         502.450         507.130         507.530
  20.000         501.850         502.450         507.130         507.530
  30.000         501.850         502.450         507.130         507.530
  31.000         501.850         502.450         507.130         507.530
  32.000         501.850         502.450         507.130         507.530
  33.000         501.850         502.450         507.130         507.530
  34.000         501.850         502.450         507.130         607.530
  35.000         501.850         502.450         507.130         507.530
  36.000         501.850         502.450         507.130         507.530
  37.000         501.850         502.450         507.130         507.530
  38.000         501.850         502.450         507.130         507.530
  39.000         501.850         502.450         507.130         507.530
  40.000         501.850         502.450         507.130         507.530
  41.000         501.850         502.450         507.130         507.530
  42.000         501.850         502.450         507.130         507.530
  43.000         501.850         502.450         507.130         507.530
  44.000         501.850         502.450         507.130         507.530
  45.000         501.850         502.450         507.130         507.530
  46.000         501.850         502.450         507.130         507.530
  47.000         501.850         502.450         507.130         507.530
  48.000         501.850         502.450         507.130         507.530
  49.000         501.850         502.450         507.130         507.530
  50.000         501.850         502.450         507.130         507.530
  58.000         501.850         502.450         507.130         507.530
  60.000         501.850         502.450         507.130         507.530
  64.000         501.850         502.450         507.130         507.530
  70.000         501.850         502.450         507.130         507.530
  80.000         501.850         502.450         507.130         507.530

*************************************************************

=======================================================
SUBROUTINE INSECT COMPUTES THE INTERSECTION OF THE
SIDESLOPES WITH THE EXISTING GROUND AT EACH STA.

================ INTERSECTION POINTS ================

 STA NO      LEFT HAND SIDESLOPE      RIGHT HAND SIDESLOPE
           GRADE  ELEV    DIST       GRADE  ELEV    DIST
   0.00      7   485.51   241.53       7   514.00   233.26
  10.00      7   485.51   241.53       7   514.00   233.26
  20.00      7   485.51   241.53       7   514.00   233.26
  30.00      7   485.51   241.53       7   514.00   233.26
  31.00      7   485.51   241.53       7   514.00   233.26
  32.00      7   485.51   241.53       7   514.00   233.26
  33.00      7   485.51   241.53       7   514.00   233.26
  34.00      7   485.51   241.53       7   514.00   233.26
```

Figure 22. (continued)

35.00	7	485.51	241.53	7	514.00	233.26
36.00	7	485.51	241.53	7	514.00	233.26
37.00	7	485.51	241.53	7	514.00	233.26
38.00	7	485.51	241.53	7	514.00	233.26
39.00	7	485.51	241.53	7	514.00	233.26
40.00	7	485.51	241.53	7	514.00	233.26
41.00	7	485.51	241.53	7	514.00	233.26
42.00	7	485.51	241.53	7	514.00	233.26
43.00	7	485.51	241.53	7	514.00	233.26
44.00	7	485.51	241.53	7	514.00	233.26
45.00	7	485.51	241.53	7	514.00	233.26
46.00	7	485.51	241.53	7	514.00	233.26
47.00	7	485.51	241.53	7	514.00	233.26
48.00	7	485.51	241.53	7	514.00	233.26
49.00	7	485.51	241.53	7	518.57	265.27
50.00	7	485.51	241.53	7	514.00	233.26
58.00	7	485.51	241.53	7	514.00	233.26
60.00	7	485.51	241.53	7	514.00	233.26
64.00	7	485.51	241.53	7	514.00	233.26
70.00	7	485.51	241.53	7	514.00	233.26
80.00	7	485.51	241.53	7	514.00	233.26

==

AREA WITHIN THE LIMIT OF GRADING 3801495.91SQFT

==

SUBROUTINE XSECT COMPUTES CROSS SECTIONAL AREAS
FOR EACH STA, VOLUME BETWEEN STAS, AND CUMULATIVE
VOLUME. FILL AREAS ARE GIVEN A + SIGN AND CUT AREAS
ARE INDICATED BY A - SIGN. THE TOTAL MOVED COLUMN IS
THAT VOLUME OF EARTH TO BE EXCAVATED BETWEEN THE STATIONS
THIS MATERIAL MAY BE EXCESS TO THE STATION OR REQUIRED BY
THE STATION FOR FILL.

================================ VOLUMES ================================

STA NC	CROSS SECTION AREAS(SF)	VOLUME BETWEEN STATIONS(CY)	CUMULATIVE VOLUME(CY)	TOTAL MOVED
		0.00	0.00	0.00
0.00	-12.12			
		-448.74	-448.74	-112129.35
10.00	-12.12			
		-448.74	-897.49	-112129.35
20.00	-12.12			
		-448.74	-1346.23	-112129.35
30.00	-12.12			
		-44.87	-1391.11	-11212.93
31.00	-12.12			
		-44.87	-1435.98	-11212.93
32.00	-12.12			
		-44.87	-1480.86	-11212.93
33.00	-12.12			
		-44.87	-1525.73	-11212.93
34.00	-12.12			
		-44.87	-1570.61	-11212.93
35.00	-12.12			
		-44.87	-1615.48	-11212.93
36.00	-12.12			

Figure 22. (continued)

		-44.87	-1660.36	-11212.93
37.00	-12.12			
		-44.87	-1705.23	-11212.93
38.00	-12.12			
		-44.87	-1750.10	-11212.93
39.00	-12.12			
		-44.87	-1794.98	-11212.93
40.00	-12.12			
		-44.87	-1839.85	-11212.93
41.00	-12.12			
		-44.87	-1884.73	-11212.93
42.00	-12.12			
		-44.87	-1929.60	-11212.93
43.00	-12.12			
		-44.87	-1974.48	-11212.93
44.00	-12.12			
		-44.87	-2019.35	-11212.93
45.00	-12.12			
		-44.87	-2064.23	-11212.93
46.00	-12.12			
		-44.87	-2109.10	-11212.93
47.00	-12.12			
		-44.87	-2153.98	-11212.93
48.00	-12.12			
		-3313.27	-5467.25	-14409.88
49.00	-1777.05			
		-3313.27	-8780.52	-14409.88
50.00	-12.12			
		-359.00	-9139.52	-89703.48
58.00	-12.12			
		-89.75	-9229.27	-22425.87
60.00	-12.12			
		-179.50	-9408.77	-44851.74
64.00	-12.12			
		-269.25	-9678.01	-67277.61
70.00	-12.12			
		-448.74	-10126.76	-112129.35
80.00	-12.12			

TOTAL VOLUME TO BE MOVED -903428.68

****

Figure 22. (continued)

EXISTING CONDITIONS

STA NO	LS ELEV	CL ELEV	RS ELEV	EXISTING SLOPE	PROPOSED SLOPE
0.000	500.000	500.000	500.000	0.000	0.000
10.000	500.000	500.000	500.000	0.000	0.000
20.000	500.000	500.000	500.000	0.000	0.000
30.000	500.000	500.000	500.000	0.000	0.000
31.000	500.000	500.000	500.000	0.000	0.000
32.000	500.000	500.000	500.000	0.000	0.000
33.000	500.000	500.000	500.000	0.000	0.000
34.000	500.000	500.000	500.000	0.000	-1.000
35.000	500.000	500.000	500.000	0.000	-1.000
36.000	500.000	500.000	500.000	0.000	-.500
37.000	496.000	496.000	496.000	-4.000	-.500
38.000	496.000	496.000	496.000	0.000	-.500
39.000	496.000	496.000	496.000	0.000	-.500
40.000	496.000	496.000	496.000	0.000	.500
41.000	496.000	496.000	496.000	0.000	.500
42.000	496.000	496.000	496.000	0.000	.500
43.000	500.000	500.000	500.000	4.000	.500
44.000	500.000	500.000	500.000	0.000	1.000
45.000	500.000	500.000	500.000	0.000	1.000
46.000	500.000	500.000	500.000	0.000	0.000
47.000	500.000	500.000	500.000	0.000	0.000
48.000	500.000	500.000	500.000	0.000	0.000
49.000	500.000	500.000	500.000	0.000	0.000
50.000	500.000	500.000	500.000	0.000	0.000
58.000	500.000	500.000	500.000	0.000	0.000
60.000	500.000	500.000	500.000	0.000	0.000
64.000	500.000	500.000	500.000	0.000	0.000
70.000	500.000	500.000	500.000	0.000	0.000
80.000	500.000	500.000	500.000	0.000	0.000

```
 VERTICAL CURVE IS NECESSARY AT STA  34.00
  6.061  STATIONS WHERE USED AT THIS STATION
TO HOLD THE GRADE CHANGE TO  .1650  PER 100 FEET

 VERTICAL CURVE IS NECESSARY AT STA  36.00
  3.030  STATIONS WHERE USED AT THIS STATION
TO HOLD THE GRADE CHANGE TO  .1650  PER 100 FEET
THE VERTICAL CURVES REQUIRED AT STATION 34.000AND 35.000CONFLICT****************************************************************************
*****************************************************************
```

Note: This data set required vertical curves which interfered with each other; therefore, the above message is printed and the output terminates. If another data set was in the data file, it would run.

Figure 22. (continued)

```
PROGRAM MAIN        73/74    OPT=1                    FTN 4.8+528         82/10/21. 11.55.29        PAGE     1

              PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
              DIMENSION E(50,15),G(50),GT(50)
C              THIS PROGRAM REQUIRES INPUT FOR NON SYMERTRIC CROSS SECTIONS
              DIMENSION S(8),XS(12),INGR(50),INGL(50)
              INTEGER M,K
              WRITE(6,4005)
         4005 FORMAT("1 THIS PROGRAM WILL CALCULATE THE ELEVATIONS OF A FINISH"
             C,/,1X,"GRADE AND THE VOLUMES OF THE CUT OR FILLS REQUIRED TO",/,
             C1X,"ACHIEVE TH T GRADE.  THE EXISTING ELEVATIONS,DESIRED SLOPE",/,
             C1X,"BETWEEN STATIONS,AND THE DESIRED CROSS SECTION SLOPES AND "
             C,/,1X,"WIDTHS MUST BE PROVIDED.",//)
              KI=1
              READ(5,*)K
C             THE VALUE OF K IS THE NUMBER OF SETS OF DATA TO BE
C              PROCESSED.  THE COUNTER KI COUNTS THOES SETS ALREADY
C              PROCESSED.
C
C              M IS THE NUMBER OF STATIONS IN THE DATA SET.
C              THE E ARRAY CONTAINS ALL OF THE EVELATIONS OF VARIOUS
C              POINTS IN ANY GIVEN CROSS SECTION.  SEE THE USERS MANUAL
C             FOR EXACT DEFINATIONS.
C              INGR,INGL REPRESENT THE TOE SLOPE ON THE RIGHT AND LEFT
C              SIDE OF THE SECTION RESPECTIVLY.
C               G IS THE PROPOSED GRADE FROM THE ITH STATION TO THE ITH+1
C              STATION.
            6 READ(5,*)M
              DO 77 JI=1,M
              READ(5,*)E(JI,1),E(JI,2),E(JI,3),E(JI,4),G(JI),INGR(JI),INGL(JI)
           77 CONTINUE
              M1=M-1
              READ(5,*)E(1,7)
              MN=8
              DO 9 JK=1,MN
              READ(5,*)S(JK)
            9 CONTINUE
C              S IS THE SLOPE OF THE CROSS SECTION INPUT FROM LEFT TO RIGHT
C              THE SIGN CONVETION IS AS YOU MOVE FROM CENTERLINE OUT POSTIVE
C               IS UPWARD AND NEGITIVE IS DOWNWARD.
              READ(5,*)(XS(I),I=2,9)
C              XS IS THE WIDTH OF EACH TRANSVERSE SECTION.  EIGHT VALUES
C              MUST BE INPUT.
              DO 3115 I=1,M
              E(1,5)=0.0
              J=I+1
              E(J,5)=(E(J,3)-E(I,3))/(E(J,1)-E(I,1))
         3115 CONTINUE
              WRITE(6,305)
          305 FORMAT("1",T30,"EXISTING CONDITIONS")
              WRITE(6,306)
          306 FORMAT(/,T59,"EXISTING",T74,"PROPOSED")
              WRITE(6,3120)
         3120 FORMAT(/,T4,"STA NO",T15,"LS ELEV",T30,"CL FLEV",T45,"RS ELEV",
             CT60,"SLOPE",T75,"SLOPE",/)
              DO 3140 I=1,M
              WRITE(6,3135)E(I,1),E(I,2),E(I,3),E(I,4),E(I,5),G(I)
         3135 FORMAT(T2,F7.3,T15,F7.3,T30,F7.3,T45,F7.3,T60,F7.3,T75,F7.3)
         3140 CONTINUE
```

Figure 23. Program Listing.

```
   80 DO 4214 I=1,M
      J=I+1
      E(J,7)=((E(J,1)-E(I,1))*G(I))+E(I,7)
 4214 CONTINUE
      READ(5,*)GMAX
C      GMAX IS THE MAXIUM GRADECHANGE ALLOWED PER 100 FEET
C      GT IS A POINTER ARRAY WHICH INDICATES AT WHICH STATIONS
C        THERE ARE VERTERCIAL CURVERS REQUIRED
      DO 140 J=1,50
      GT(J)=0.0
  140  CONTINUE
      M2=M-2
      DO 130 J=1,M2
      JK=J+1
      IF(G(J).EQ.G(JK)) GO TO 130
      GT(J)=1.0
  130 CONTINUE
      SAVD=0.0
C      SAVED AND TEST ARE VALUES TO DETERMINE IF VERTICAL CURVERS
C      INTERFERE WITH THE PRECEEDING VERTICAL CURVE.
      TEST=0.0
C      THIS LOOP DETERMINES IF MORE THAN ONE VERTICAL CURVE
C       IS IN THE SECTION.
      DO 190 J=1,M1
      IF(GT(J).NE.1.0) GO TO 190
      IF(NNTEST.EQ.1.0) GO TO 191
      NNTEST=1.0
      GO TO 190
  191 TEST=1.0
  190 CONTINUE
      DO 150 J=1,M1
      IF(GT(J).NE.1.0)GO TO 150
      JK=J+1
      WRITE(6,4221)E(JK,1)
 4221 FORMAT(/,"A VERTICAL CURVE IS NECESSARY AT STA.",F6.2)
      F=G(J)-G(JK)
      IF(F.GT.0.0) GO TO 100
       F=-F
  100 B=F/GMAX
      WRITE(6,4225)B,GMAX
 4225 FORMAT(1X,F7.3,2X,"STATIONS WHERE USED AT THIS STATION",/,
     C1X,"TO HOLD THE GRADE CHANGE TO",1X,F6.4,1X," PER 100 FEET")
      VS=E(JK,1)
      ELEVVS=E(JK,7)
      ELEVC=ELEVVS-(G(J)*(B/2.))
C     BVC=C,EVC=D,V=VS
      C=VS-(B/2.)
      D=VS+(B/2.)
      IF(TEST.NE.1.0) GO TO 171
      IF(SAVD.LT.C) GO TO 171
      WRITE(6,153)E(J-1,1),E(J,1)
  153 FORMAT(1X,"THE VERTICAL CURVES REQUIRED AT STATION",F7.3,
     C"AND",F7.3,"CONFLICT",61("*"),/,61("*"))
      GO TO 180
  171 RGRAD=(G(JK)-G(J))/(B*2.)
      DO 4273 JL=1,M
      IF(E(JL,1).LT.C) GO TO 4273
```

Figure 23. (continued)

```
      IF(E(JL,1).GE.D) GO TO 150
      SAVD=D
  170 XSTA=E(JL,1)=C
      E(JL,7)=((XSTA**2.)*RGRAD)+(G(J)*XSTA)+ELEVC
 4273 CONTINUE
  150 CONTINUE
      WRITE(6,4290)
 4290 FORMAT(/,7X,32("*")," CROSS SECTION ",32("*"),//)
C      THESE E VALUES ARE THE FINISH ELEVATIONS AT VARIOUS POINTS
C      SEE USERS MANUAL FOR EXACT LOCATION.
      I=1
 4725 E(I,11)=E(I,7)+(XS(5)*S(4))
      E(I,10)=E(I,11)+(XS(4)*S(3))
      E(I,9)=E(I,10)+(XS(3)*S(2))
      E(I,8)=E(I,9)+(XS(2)*S(1))
      E(I,12)=E(I,7)+(XS(6)*S(5))
      E(I,13)=E(I,12)+(XS(7)*S(6))
      E(I,14)=E(I,13)+(XS(8)*S(7))
      E(I,15)=E(I,14)+(XS(9)*S(8))
      I=I+1
      MIZ=M+1
      IF(I.EQ.MIZ) GO TO 4780
      GO TO 4725
 4780 WRITE(6,4781)
 4781 FORMAT(T2,"STA",T22,"BACKL",T42,"DITL",T62,"SHL",T82,"PVMTL",T102,
     C1X,"CL",/)
      WRITE(6,300)(S(I),I=1,4),(XS(I),I=2,5)
  300 FORMAT(T2,"SLOPE",T32,F5.3,T52,F5.3,T72,F5.3,T92,F5.3,/,
     CT2,"WIDTHS",T32,F6.1,T52,F6.1,T72,F6.1,T92,F6.1)
      DO 4800 I=1,M
      WRITE(6,4795)E(I,1),E(I,8),E(I,9),E(I,10),E(I,11),E(I,7)
 4795 FORMAT(T2,F7.3,T22,F7.3,T42,F7.3,T62,F7.3,T82,F7.3,T102,F7.3)
 4800 CONTINUE
      WRITE(6,4815)
 4815 FORMAT(//,T2,"STA",T22,"PVMTR",T42,"SHR",T62,"DITR",T82,"BACKR",/)
      WRITE(6,301)(S(I),I=5,8),(XS(I),I=6,9)
  301 FORMAT(T2,"SLOPE",T12,F5.3,T32,F5.3,T52,F5.3,T72,F5.3,/,
     CT2,"WIDTHS",T12,F6.1,T32,F6.1,T52,F6.1,T72,F6.1)
      DO 4835 I=1,M
      WRITE(6,4830)E(I,1),E(I,12),E(I,13),E(I,14),E(I,15)
 4830 FORMAT(T2,F7.3,T22,F7.3,T42,F7.3,T62,F7.3,T82,F7.3)
 4835 CONTINUE
      CALL XSECT(E,M,XS,INGR,INGL)
  180 IF(KI.EQ.K) GO TO200
      KI=KI+1
      GO TO 6
  200 END
```

Figure 23. (continued)

```
      C
      C     SUBROUTINE XSECT
      C
      C     THIS SUBROUTINE COMPUTES THE CROSS SECTIONAL AREA OF
      C     EACH STATION, AND OUTPUTS THE VOLUME AND CUCULATIVE
      C     VOLUME BETWEEN STATIONS. IT ALSO COORDINATES THE
      C     OUTPUTS OF THE INSECT AND MASBAL SUBROUTINES.
      C
            SUBROUTINE XSECT(E,M,XS,INGR,INGL)
            DIMENSION E(50,15)
            DIMENSION INGR(50),INGL(50)
            DIMENSION XINSR(50,2),XINSL(50,2)
            DIMENSION YS(12),XS(12),XSAP(13)
            DIMENSION XSA(50),VOLMX(50)
            DIMENSION VOL(50),CVOL(50),VOLM(50)
            DIMENSION X(52),Y(52)
            DIMENSION YMAX(50)
            DIMENSION BUF(512)
            CALL INSECT(E,M,XINSR,XINSL,INGR,INGL,XS,NTEST)
            IF(NTEST.EQ.1) RETURN
            DO 5000 J=1,M
            YS(2)=XINSL(J,1)-E(J,8)
            YS(3)=XINSL(J,1)-E(J,9)
            YS(4)=XINSL(J,1)-E(J,10)
            YS(5)=XINSL(J,1)-E(J,11)
            YS(6)=XINSL(J,1)-E(J,7)
            YS(7)=XINSR(J,1)-E(J,12)
            YS(8)=XINSR(J,1)-E(J,13)
            YS(9)=XINSR(J,1)-E(J,14)
            YS(10)=XINSR(J,1)-E(J,15)
            YS(11)=XINSR(J,1)-E(J,3)
            YS(12)=XINSL(J,1)-E(J,3)
            XS(1)=XINSL(J,2)
            XS(11)=XINSR(J,2)
            XSA(J)=0.0
            VOLM(J)=0.0
            XSAP(1)=-0.5*(XS(1)-XS(2)-XS(3)-XS(4)-XS(5))*YS(2)
            XSAP(10)=-0.5*(XS(11)-XS(6)-XS(7)-XS(8)-XS(9))*YS(10)
            XSAP(11)=-(YS(12)*XS(1)*0.5)
            XSAP(12)=-(YS(11)*XS(11)*0.5)
            DO 300 I=2,9
            IF(YS(I).EQ.0.0) GO TO 303
            IF(YS(I).LT.0.0) GO TO 301
            IF(YS(I+1).GT.0.0) GO TO 303
            GO TO 302
        301 IF(YS(I+1).LT.0.0) GO TO 303
        302 YX=YS(I)-YS(I+1)
             SP=YX/XS(I)
            A1=-((YS(I)**2)/SP)*0.5
             A2=((YS(I+1)**2)/SP)*0.5
             XSAP(I)=A1+A2
            IF(A1.GT.0.0) GO TO 304
            VOLM(J)=VOLM(J)+A1
        304 IF(A2.GT.0.0) GO TO 300
            VOLM(J)=VOLM(J)+A2
            GO TO 300
        303 XSAP(I)=-((YS(I)+YS(I+1))/2.0)*XS(I)
```

Figure 23. (continued)

```
SUBROUTINE XSECT       73/74    OPT=1                    FTN 4.8+528        82/10/21. 11.55.29        PAGE     2

              IF(XSAP(I).GT.0.0) GO TO 300
              VOLM(J)=VOLM(J)+XSAP(I)
          300 CONTINUE
              IF(XSAP(1).GT.0.0) GO TO 310
              VOLM(J)=VOLM(J)+XSAP(1)
          310 DO 311 I=10,12
              IF(XSAP(I).GT.0.0) GO TO 311
              VOLM(J)=VOLM(J)+XSAP(I)
          311 CONTINUE
              DO 202 I=1,12
              XSA(J)=XSA(J)+XSAP(I)
          202 CONTINUE
         5000 CONTINUE
              VOL(1)=0.0
              DO 5002 J=2,M
              VOL(J)=(XSA(J-1)+XSA(J))*(E(J,1)-E(J-1,1))*100.0/54.0
              VOLMX(J)=(VOLM(J-1)+VOLM(J))*(E(J,1)-E(J-1,1))*100.0/54.0
         5002 CONTINUE
              CVOL(1)=0.0
              CVOLM=0.0
              SUM=0.0
              DO 5003 J=2,M
              CVOL(J)=VOL(J)+SUM
              SUM=CVOL(J)
              CVOLM=CVOLM+VOLMX(J)
         5003 CONTINUE
              WRITE(6,5004)
         5004 FORMAT(///,51("="))
              WRITE(6,5005)
         5005 FORMAT(1X,"SUBROUTINE XSECT COMPUTES CROSS SECTIONAL AREAS",/,
             C1X,"FOR EACH STA. VOLUME BETWEEN STAS, AND CUMULATIVE",/,
             C1X,"VOLUME. FILL AREAS ARE GIVEN A + SIGN AND CUT AREAS",/,
             C1X,"ARE INDICATED BY A - SIGN.  THE TOTAL MOVED COLUMN IS",/,
             C1X,"THAT VOLUME OF EARTH TO BE EXCAVATED BETWEEN THE STATIONS",/,
             C1X,"THIS MATERIAL MAY BE EXCESS TO THE STATION OR REQUIRED BY",/,
             C1X,"THE STATION FOR FILL.",//)
              WRITE(6,5006)
         5006 FORMAT(//,32("="),"  VOLUMES ",32("="),//)
              WRITE(6,5007)
         5007 FORMAT(2X,"STA NO",6X,"CROSS SECTION",6X,"VOLUME BETWEEN",6X,"CUMU
             CLATIVE",8X,"TOTAL MOVED")
              WRITE(6,5008)
         5008 FORMAT(18X,"AREAS(SF)",6X,"STATIONS(CY)",11X,"VOLUME(CY)",/)
              DO 5009 J=1,M
              WRITE(6,5010)VOL(J),CVOL(J),VOLMX(J)
         5010 FORMAT(27X,F15.2,4X,F15.2,4X,F15.2)
              WRITE(6,5011)E(J,1),XSA(J)
         5011 FORMAT(2X,F6.2,2X,F15.2)
         5009 CONTINUE
              WRITE(6,5012)CVOLM
         5012 FORMAT(//,T30,"TOTAL VOLUME TO BE MOVED",F18.2)
              WRITE(6,5013)
         5013 FORMAT(///,61("="))
              RETURN
              END
```

Figure 23. (continued)

```
      C
      C     SUBROUTINE INSECT
      C
      C     THIS SUBROUTINE APPROXIMATES THE INTERSECTION
      C     POINT OF THE ROAD SIDESLOPES WITH THE
      C     EXISTING GROUND.  INPUT CONSISTS OF THE
      C     SIDESLOPE GRADE AT EACH STATION.
      C
            SUBROUTINE INSECT(E,M,XINSR,XINSL,INGR,INGL,XS,NTEST)
            DIMENSION E(50,15)
            DIMENSION XINSR(50,2),XINSL(50,2)
            DIMENSION INGR(50),INGL(50),XS(12)
            DO 6010 I=1,M
            XINSR(I,1)=0.0
            XINSR(I,2)=0.0
            XINSL(I,1)=0.0
            XINSL(I,2)=0.0
       6010 CONTINUE
            NTEST=0
            XL=XS(2)+XS(3)+XS(4)+XS(5)
            XR=XS(7)+XS(8)+XS(9)+XS(6)
            WRITE(6,6011)
       6011 FORMAT(///,61("*"),///,56("="),/,
           C1X,"SUBROUTINE INSECT COMPUTES THE INTERSECTION OF THE",/,
           C1X,"SIDESLOPES WITH THE EXISTING GROUND AT EACH STA.",//)
            DO 100 J=1,M
            TCB=(E(J,3)-E(J,4))/(XS(6))
            IF(TCB.NE.INGR(J)) GO TO 101
            WRITE(6,102)E(J,1)
        102 FORMAT("THE SLOPE CHOOSEN AT STATION",F7.3,"RIGHT SIDE IS"
           C1X,"PARALLEL TO THE EXISTING GROUND")
            NTEST=1
            GO TO 100
        101 A=-(TCB*(XR-XS(6)))+E(J,4)
            IF(E(J,15).EQ.A) GO TO 103
            IF(E(J,15).LT.A) GO TO 104
            CALL GREATER(A,E(J,15),INGR(J),TCB,D,ED)
            XINSR(J,1)=E(J,15)-ED
            XINSR(J,2)=D+XR
            GO TO 100
        103 XINSR(J,1)=E(J,15)
            XINSR(J,2)=XR
            GO TO 100
        104 CALL LESSER(A,E(J,15),INGR(J),TCB,D,ED)
            XINSR(J,1)=ED+E(J,15)
            XINSR(J,2)=D+XR
        100 CONTINUE
            DO 110 J=1,M
            TCA=(E(J,3)-E(J,2))/(XS(5))
            IF(TCA.NE.INGL(J)) GO TO 111
            NTEST=1
            WRITE(6,112)E(J,1)
        112 FORMAT("THE SLOPE CHOOSEN AT STATION",F7.3,"LEFT SIDE IS"
           C1X,"PARALLEL TO THE EXISTING GROUND")
            GO TO 110
        111 A=-(TCA*(XL-XS(5)))+E(J,2)
            IF(E(J,8).EQ.A) GO TO 113
```

Figure 23. (continued)

```
      IF(E(J,8).LT.A) GO TO 114
       CALL GREATER(A,E(J,8),INGL(J),TCA,D,ED)
      XINSL(J,1)=E(J,8)-ED
      XINSL(J,2)=D+XL
      GO TO 110
  113 XINSL(J,1)=E(J,8)
      XINSL(J,2)=(XL)
      GO TO 110
  114 CALL LESSER(A,E(J,8),INGL(J),TCA,D,ED)
      XINSL(J,1)=ED+E(J,8)
      XINSL(J,2)=D+(XL)
  110 CONTINUE
      IF(NTEST.EQ.1) RETURN
      WRITE(6,6050)
 6050 FORMAT(//,10("="),"  INTERSECTION POINTS ",17("="),//)
      WRITE(6,6051)
 6051 FORMAT(2X,"STA NO",6X," LEFT HAND SIDESLOPE",4X,"RIGHT HAND SIDESL
     COPE")
      WRITE(6,6052)
 6052 FORMAT(13X,"GRADE  ELEV   DIST",9X,"GRADE  ELEV   DIST",/)
      DO 6053  J=1,M
      WRITE(6,6054)E(J,1),INGL(J),XINSL(J,1),XINSL(J,2),INGR(J),XINSR(J,
     C1),XINSR(J,2)
 6054 FORMAT(2X,F6.2,6X,I2,2X,F6.2,1X,F8.2,7X,I2,2X,F6.2,1X,F8.2)
 6053 CONTINUE
      WRITE(6,6060)
 6060 FORMAT(//,56("="))
      ACUM=0.0
      A=0.0
      M1=M-1
      DO 200 JK=1,M1
      JK1=JK+1
      W=((XINSL(JK,2)+XINSR(JK,2))+XINSL(JK1,2)+XINSR(JK1,2))/2.0
      A=W*100.0*(E(JK1,1)-E(JK,1))
      ACUM=ACUM+A
  200 CONTINUE
      WRITE(6,201)ACUM
  201 FORMAT(1X,//,1X,"AREA WITHIN THE LIMIT OF GRADING",F20.2,"SQFT")
      RETURN
      END
```

Figure 23. (continued)

```
SUBROUTINE GREATER      73/74    OPT=1                    FTN 4.8+528        82/10/21. 11.55.29        PAGE     1

              C
              C
              C   SUBROUTINE GREATER
              C
              C
                    SUBROUTINE GREATER(A,S,ING,TC,D,E)
                    DE=S-A
                    SN=1.0/ING
                    D=DE/(SN-TC)
                    E=D*(SN)
                    RETURN
                     END
```

```
SUBROUTINE LESSER       73/74    OPT=1                    FTN 4.8+528        82/10/21. 11.55.29        PAGE     1

              C
              C
              C      SUBROUTINE LESSER
              C
              C
                     SUBROUTINE LESSER(A,S,ING,TC,D,E)
                    DE=(A-S)
                    SN=1.0/ING
                    D=DE/(SN+TC)
                    E=D*SN
                    RETURN
                    END
```

Figure 23. (continued)

AD-A128 323 EVALUATION OF DESIGN CRITERION OF THE STRATEGIC EXPEDITIONARY LANDING FIELD(U) GEORGIA INST OF TECH ATLANTA SCHOOL OF CIVIL ENGINEERING R E BURGOYNE

2/2

UNCLASSIFIED DEC 82 N66314-70-A-0067 F/G 1/5 NL

END
DATE
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6-83
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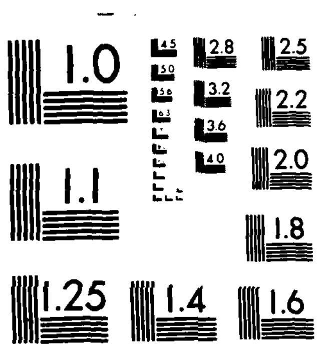
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1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

Table 10. List of Variables.

Variable	Definition
K	number of data sets in this data file
KI	number of data sets this run which have been completed
M	number of station in this data set maximum 50
E(I,1)	station number
E(I,2)	existing ground elevation left side
E(I,3)	existing ground elevation centerline
E(I,4)	existing ground elevation right side
E(I,5)	the calculated value of existing slope from the previous station to this station
E(I,6)	not used
E(I,7-15)	finish elevations at various points in the cross section. See Fig. 19 for exact location
S(I)	the different slopes in the cross section. Positive if rising from the centerline. See Fig. 19 for location
G(I)	the desired finish grade from Station I to Station I + 1
GMAX	the maximum rate of grade change per 100 feet in terms of percent
INGR(I),INGL(I)	the desired toe slope at Station I to the right side and left side, respectively
YS(I)	the difference in existing grade and finish grade. See Fig. 19 for exact location

Table 10. (continued)

Variable	Definition
XSAP(I)	the area of a section of the cross section area. See Fig. 19
XSA(J)	the algebraic sum of the XSAP(I) at Station J
VOLM(J)	the sum of all XSAP(I) having a negative value; that is, being a cut below existing grade
VOL(J)	the net earthwork between Stations J-1 and J
VOLM(J)	the volume of cut between Stations J-1 and J
CVOL(J)	the sum of all VOL(I) for I = 1, J
CVOLM	the sum of all VOLM(I)
XINSR(I,1)	the elevation of the toe slope and existing ground intersection on the right side
XINSL(I,1)	same as XINSR(I,1) except left side
XINSR(I,2)	the distance from center line that the toe slope and existing ground intersect on the right side
XINSL(I,2)	same as XINSR(I,2) except on the left side

APPENDIX D

SAMPLE CONSTRUCTION EFFORT CALCULATIONS

For the purposes of this sample, the data of the standard SELF model on level ground is used. In evaluating the construction effort, five major items of work were considered. They are: clearing and grubbing, fill to the site, soil to be cut and filled within the confines of the site, the final grading and compaction of the area to have matting installed over it, and drainage. Clearing and grubbing is the removal of all unwanted surface material over the entire area within the limits of grading. Fill to the site is the net amount of soil hauled into the site from outside the limits of grading. This quantity was minimized in the development of the various models as the final elevations were normally chosen to balance the cut and fill requirement. (There were no models developed which had a net cut for the site.) Soil to be cut and filled within the site is the quantity of material moved within the site to build the crown and valley of the cross section. The final grading is the additional effort required to grade to an exact level and smoothness to allow for the placement of matting. The area this extra effort was applied to is that which will be covered by

matting. Drainage effort is limited to that required to drain the storm run off from the infield.

The following production factors were used: (7)

Clearing and grubbing	2.1	mandays/1000 yds^2
Fill (dig, load, haul, spread, compact)	10	mandays/1000 yds^2
Earth moved	10	mandays/1000 yds^3
Final grading and compaction	3.5	mandays/1000 yds^2
Drainage		
Culvert installation	60	mandays/1000 lnft
Excavation and back fill	9.9	mandays/1000 yds^3

From the Earthwork program output, Fig. 25, the following quantities can be obtained:

Area within the limit of grading:	3,492,793 ft^2
Net fill	0 yds^3
Earth moved	53.066 yds^3

The area of the pavement in the model SELF as in Fig. 10 is 1,942,560 ft^2. The drainage must be calculated based on the quantity of run off created by the design storm. The Rational Method of estimating run off was used. The design storm intensity of 3 inches per hour was used as this is the most intense storm in Fig. 6-3 of TM5-330 for any location in the world. Applying these factors, a quantity of runoff of 166 cfs was determined. Choosing a 24-inch culvert, each is capable of delivering 11 cfs. (3) Therefore, 16 culverts are required for the drainage of the

EXISTING CONDITIONS

STA NO	LS ELEV	CL ELEV	RS ELEV	EXISTING SLOPE	PROPOSED SLOPE
0.000	500.000	500.000	500.000	0.000	0.000
10.000	500.000	500.000	500.000	0.000	0.000
20.000	500.000	500.000	500.000	0.000	0.000
30.000	500.000	500.000	500.000	0.000	0.000
31.000	500.000	500.000	500.000	0.000	0.000
32.000	500.000	500.000	500.000	0.000	0.000
33.000	500.000	500.000	500.000	0.000	0.000
34.000	500.000	500.000	500.000	0.000	0.000
35.000	500.000	500.000	500.000	0.000	0.000
36.000	500.000	500.000	500.000	0.000	0.000
37.000	500.000	500.000	500.000	0.000	0.000
38.000	500.000	500.000	500.000	0.000	0.000
39.000	500.000	500.000	500.000	0.000	0.000
40.000	500.000	500.000	500.000	0.000	0.000
41.000	500.000	500.000	500.000	0.000	0.000
42.000	500.000	500.000	500.000	0.000	0.000
43.000	500.000	500.000	500.000	0.000	0.000
44.000	500.000	500.000	500.000	0.000	0.000
45.000	500.000	500.000	500.000	0.000	0.000
46.000	500.000	500.000	500.000	0.000	0.000
47.000	500.000	500.000	500.000	0.000	0.000
48.000	500.000	500.000	500.000	0.000	0.000
49.000	500.000	500.000	500.000	0.000	0.000
50.000	500.000	500.000	500.000	0.000	0.000
58.000	500.000	500.000	500.000	0.000	0.000
60.000	500.000	500.000	500.000	0.000	0.000
64.000	500.000	500.000	500.000	0.000	0.000
70.000	500.000	500.000	500.000	0.000	0.000
80.000	500.000	500.000	500.000	0.000	0.000

****************************** CROSS SECTION ******************************

STA	BACKL		DITL		SHL		PVHTL		CL
SLOPE		-.050		-.030		.050		.030	
WIDTHS		20.0		96.0		20.0		90.0	
0.000	498.116		499.116		501.996		500.996		498.296
10.000	498.116		499.116		501.996		500.996		498.296
20.000	498.116		499.116		501.996		500.996		498.296
30.000	498.116		499.116		501.996		500.996		498.296
31.000	498.116		499.116		501.996		500.996		498.296
32.000	498.116		499.116		501.996		500.996		498.296
33.000	498.116		499.116		501.996		500.996		498.296
34.000	498.116		499.116		501.996		500.996		498.296
35.000	498.116		499.116		501.996		500.996		498.296
36.000	498.116		499.116		501.996		500.996		498.296
37.000	498.116		499.116		501.996		500.996		498.296
38.000	498.116		499.116		501.996		500.996		498.296
39.000	498.116		499.116		501.996		500.996		498.296
40.000	498.116		499.116		501.996		500.996		498.296
41.000	498.116		499.116		501.996		500.996		498.296
42.000	498.116		499.116		501.996		500.996		498.296
43.000	498.116		499.116		501.996		500.996		498.296
44.000	498.116		499.116		501.996		500.996		498.296
45.000	498.116		499.116		501.996		500.996		498.296
46.000	498.116		499.116		501.996		500.996		498.296
47.000	498.116		499.116		501.996		500.996		498.296
48.000	498.116		499.116		501.996		500.996		498.296
49.000	498.116		499.116		501.996		500.996		498.296

Figure 24. Standard SELF Data Set.

50.000	498.116	499.116	501.996	500.996	498.296
58.000	498.116	499.116	501.996	500.996	498.296
60.000	498.116	499.116	501.996	500.996	498.296
64.000	498.116	499.116	501.996	500.996	498.296
70.000	498.116	499.116	501.996	500.996	498.296
80.000	498.116	499.116	501.996	500.996	498.296

STA		PVMTR		SHR		DITR		BACKR
SLOPE	.030		.050		-.030		-.050	
WIDTHS	90.0		10.0		78.0		10.0	
0.000		500.996		501.496		499.156		498.656
10.000		500.996		501.496		499.156		498.656
20.000		500.996		501.496		499.156		498.656
30.000		500.996		501.496		499.156		498.656
31.000		500.996		501.496		499.156		498.656
32.000		500.996		501.496		499.156		498.656
33.000		500.996		501.496		499.156		498.656
34.000		500.996		501.496		499.156		498.656
35.000		500.996		501.496		499.156		498.656
36.000		500.996		501.496		499.156		498.656
37.000		500.996		501.496		499.156		498.656
38.000		500.996		501.496		499.156		498.656
39.000		500.996		501.496		499.156		498.656
40.000		500.996		501.496		499.156		498.656
41.000		500.996		501.496		499.156		498.656
42.000		500.996		501.496		499.156		498.656
43.000		500.996		501.496		499.156		498.656
44.000		500.996		501.496		499.156		498.656
45.000		500.996		501.496		499.156		498.656
46.000		500.996		501.496		499.156		498.656
47.000		500.996		501.496		499.156		498.656
48.000		500.996		501.496		499.156		498.656
49.000		500.996		501.496		499.156		498.656
50.000		500.996		501.496		499.156		498.656
58.000		500.996		501.496		499.156		498.656
60.000		500.996		501.496		499.156		498.656
64.000		500.996		501.496		499.156		498.656
70.000		500.996		501.496		499.156		498.656
80.000		500.996		501.456		499.156		498.656

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SUBROUTINE INSECT COMPUTES THE INTERSECTION OF THE
SIDESLOPES WITH THE EXISTING GROUND AT EACH STA.

================ INTERSECTION POINTS ================

STA NO	LEFT HAND SIDESLOPE GRADE	ELEV	DIST	RIGHT HAND SIDESLOPE GRADE	ELEV	DIST
0.00	7	500.00	239.19	7	500.00	197.41
10.00	7	500.00	239.19	7	500.00	197.41
20.00	7	500.00	239.19	7	500.00	197.41
30.00	7	500.00	239.19	7	500.00	197.41
31.00	7	500.00	239.19	7	500.00	197.41
32.00	7	500.00	239.19	7	500.00	197.41
33.00	7	500.00	239.19	7	500.00	197.41
34.00	7	500.00	239.19	7	500.00	197.41

Figure 24. (continued)

35.00	7	500.00	239.19	7	500.00	197.41
36.00	7	500.00	239.19	7	500.00	197.41
37.00	7	500.00	239.19	7	500.00	197.41
38.00	7	500.00	239.19	7	500.00	197.41
39.00	7	500.00	239.19	7	500.00	197.41
40.00	7	500.00	239.19	7	500.00	197.41
41.00	7	500.00	239.19	7	500.00	197.41
42.00	7	500.00	239.19	7	500.00	197.41
43.00	7	500.00	239.19	7	500.00	197.41
44.00	7	500.00	239.19	7	500.00	197.41
45.00	7	500.00	239.19	7	500.00	197.41
46.00	7	500.00	239.19	7	500.00	197.41
47.00	7	500.00	239.19	7	500.00	197.41
48.00	7	500.00	239.19	7	500.00	197.41
49.00	7	500.00	239.19	7	500.00	197.41
50.00	7	500.00	239.19	7	500.00	197.41
58.00	7	500.00	239.19	7	500.00	197.41
60.00	7	500.00	239.19	7	500.00	197.41
64.00	7	500.00	239.19	7	500.00	197.41
70.00	7	500.00	239.19	7	500.00	197.41
80.00	7	500.00	239.19	7	500.00	197.41

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AREA WITHIN THE LIMIT OF GRADING 3492793.46SQFT -- for clearing and grubbing

===
SUBROUTINE XSECT COMPUTES CROSS SECTIONAL AREAS
FOR EACH STA, VOLUME BETWEEN STAS, AND CUMULATIVE
VOLUME. FILL AREAS ARE GIVEN A + SIGN AND CUT AREAS
ARE INDICATED BY A - SIGN. THE TOTAL MOVED COLUMN IS
THAT VOLUME OF EARTH TO BE EXCAVATED BETWEEN THE STATIONS
THIS MATERIAL MAY BE EXCESS TO THE STATION OR REQUIRED BY
THE STATION FOR FILL.

============================== VOLUMES ===============================

STA NO	CROSS SECTION AREAS(SF)	VOLUME BETWEEN STATIONS(CY)	CUMULATIVE VOLUME(CY)	TOTAL MOVED
		0.00	0.00	0.00
0.00	-.00			
		-.02	-.02	-6633.33
10.00	-.00			
		-.02	-.04	-6633.33
20.00	-.00			
		-.02	-.06	-6633.33
30.00	-.00			
		-.00	-.06	-663.33
31.00	-.00			
		-.00	-.06	-663.33
32.00	-.00			
		-.00	-.06	-663.33
33.00	-.00			
		-.00	-.06	-663.33
34.00	-.00			
		-.00	-.07	-663.33
35.00	-.00			
		-.00	-.07	-663.33
36.00	-.00			

Figure 24. (continued)

37.00	-.00	-.00	-.07	-663.33
38.00	-.00	-.00	-.07	-663.33
39.00	-.00	-.00	-.07	-663.33
40.00	-.00	-.00	-.08	-663.33
41.00	-.00	-.00	-.08	-663.33
42.00	-.00	-.00	-.08	-663.33
43.00	-.00	-.00	-.08	-663.33
44.00	-.00	-.00	-.08	-663.33
45.00	-.00	-.00	-.09	-663.33
46.00	-.00	-.00	-.09	-663.33
47.00	-.00	-.00	-.09	-663.33
48.00	-.00	-.00	-.09	-663.33
49.00	-.00	-.00	-.09	-663.33
50.00	-.00	-.00	-.09	-663.33
58.00	-.00	-.02	-.11	-5306.66
60.00	-.00	-.00	-.11	-1326.67
64.00	-.00	-.01	-.12	-2653.33
70.00	-.00	-.01	-.13	-3980.00
80.00	-.00	-.02	-.15	-6633.33

required fill

TOTAL VOLUME TO BE MOVED -53066.63

earth moved within the site

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Figure 24. (continued)

infield. Each culvert is installed under the taxiway at a length of 208 feet in a ditch three feet wide by six feet deep and will require 13.85 mandays each.

Summary

Clearing and grubbing		@ 2.1 md/1000 yds^2	815 md
Fill	0 yds^3	@10 md/1000 yds^3	0 md
Earth moved	53,066 yds^3	@10 md/1000 yds^3	531 md
Final grading	1,942.560 ft^2	@ 3.5 md/1000 yds^2	755 md
Drainage 16 culverts		@13.85 md/culvert	222 md
		Total Effort	2323 mandays